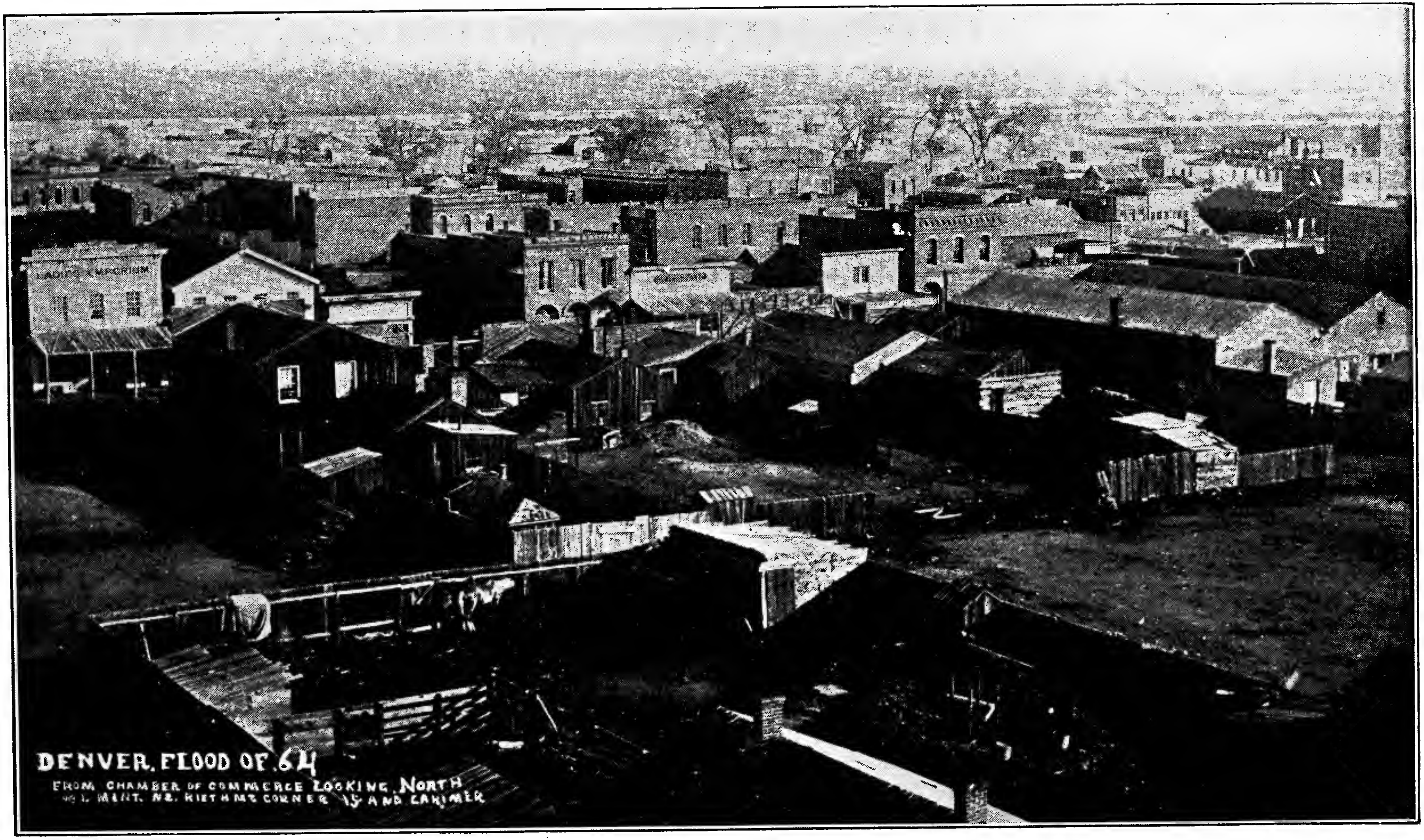
REPORT

of

CHERRY CREEK FLOOD COMMISSION

Denver, Colorado

May, 1913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REPORT

OF

Cherry Creek Flood Commission

MAY, 1913

John H. Marks

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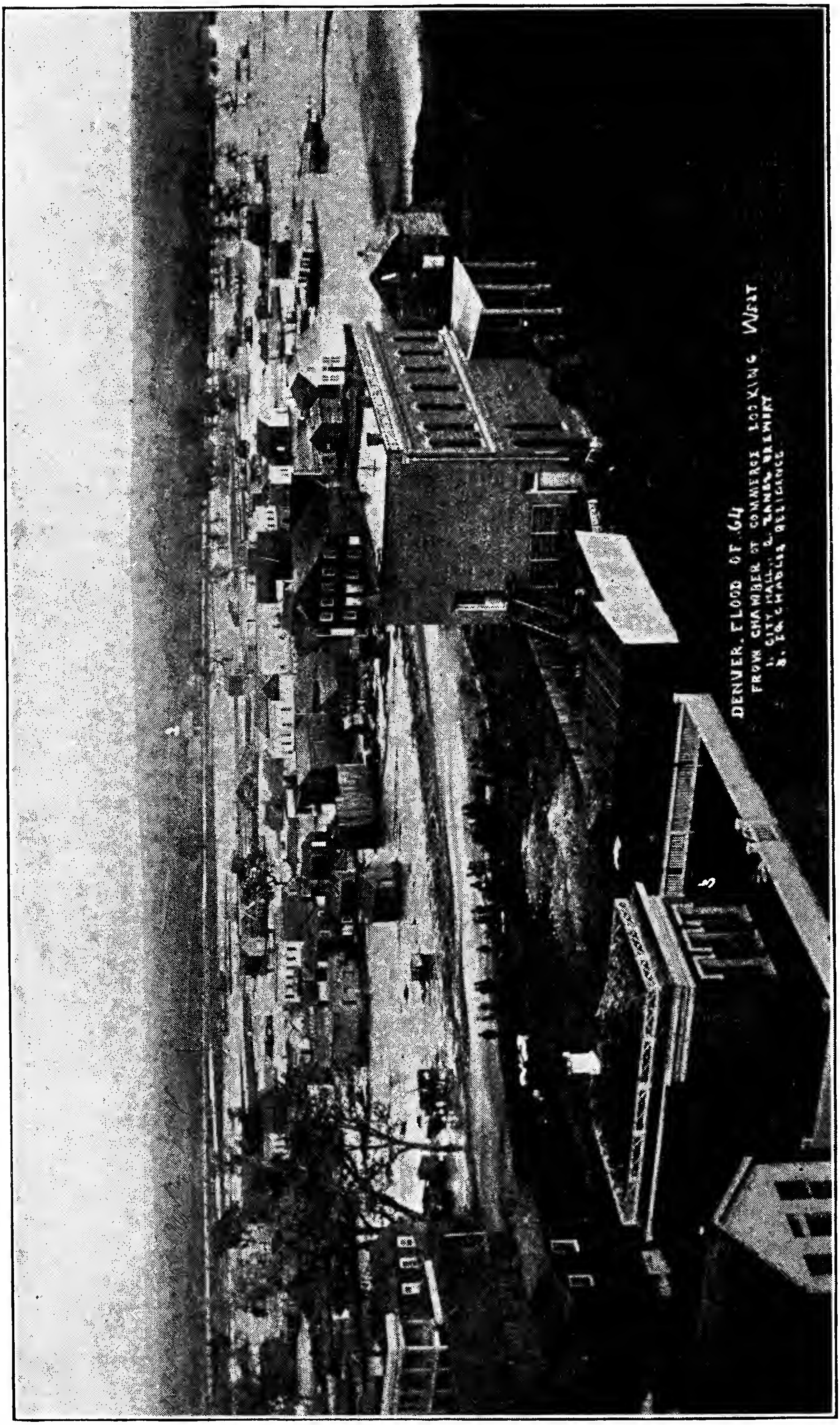
THE SMITH-BROOKS PRESS, DENVER


DENVER. FLOOD OF .64
FROM CHAMBER OF COMMERCE LOOKING WEST
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Letter of Transmittal

Denver, Colo., May 20, 1913.

The Honorable Board of Public Works,
City and County of Denver.

GENTLEMEN: Herewith is submitted a report concerning the proposed regulation and control of Cherry Creek floods. The report cannot be considered as complete, since the investigations and surveys have not been made in as great detail as is desirable. It is believed, however, that investigations have proceeded to a point where further study would merely serve to confirm the conclusions now reached. We are of the opinion, therefore, that the conclusions arrived at in this report would not be materially modified by further study, which would have in view the working-out of details rather than arrival at general conclusions.

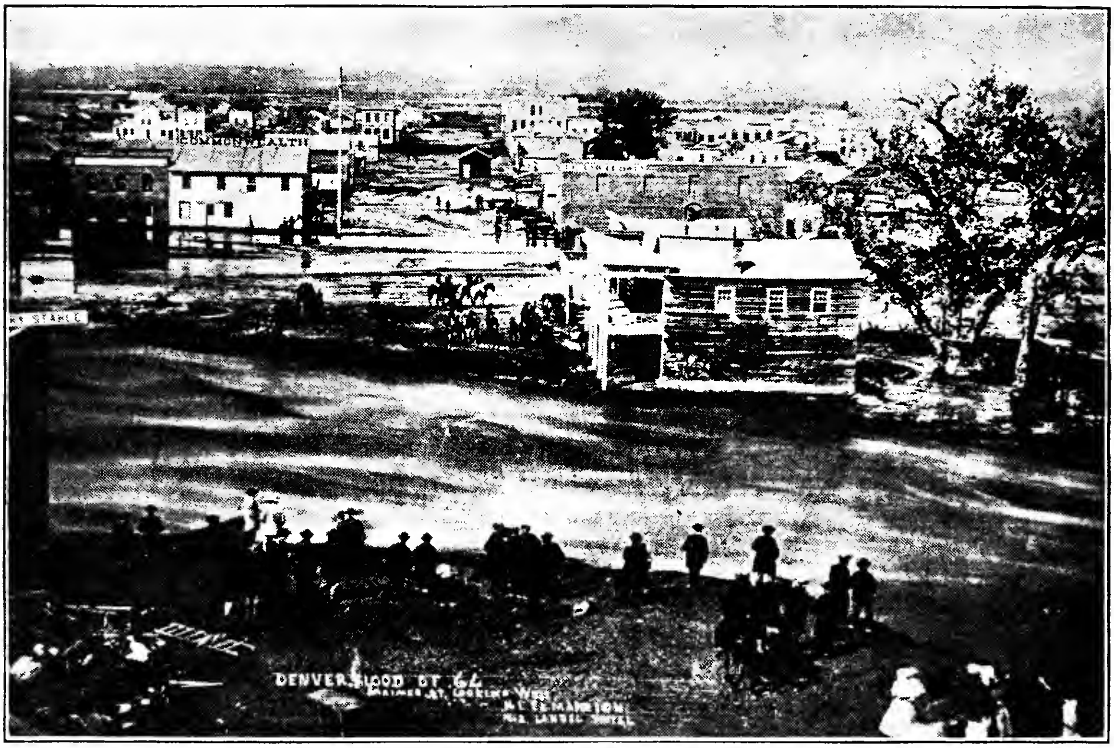
In accordance with your instructions, we have endeavored to compile this report at the lowest possible cost. It should be stated, however, that we have had a number of requests for copies of this report, and we recommend that the report be printed, in order that it may be discussed by the public with a better understanding than would be possible if conclusions alone were made public.

In submitting this report, we desire to express our obligation to the Pittsburg Flood Commission, whose report has been of great assistance to us in compiling ours. Not only have we abstracted one of the appendices of this report in its entirety, but we have adopted to a great extent the conclusions contained in the Pittsburg flood report, using them as a model for our own.

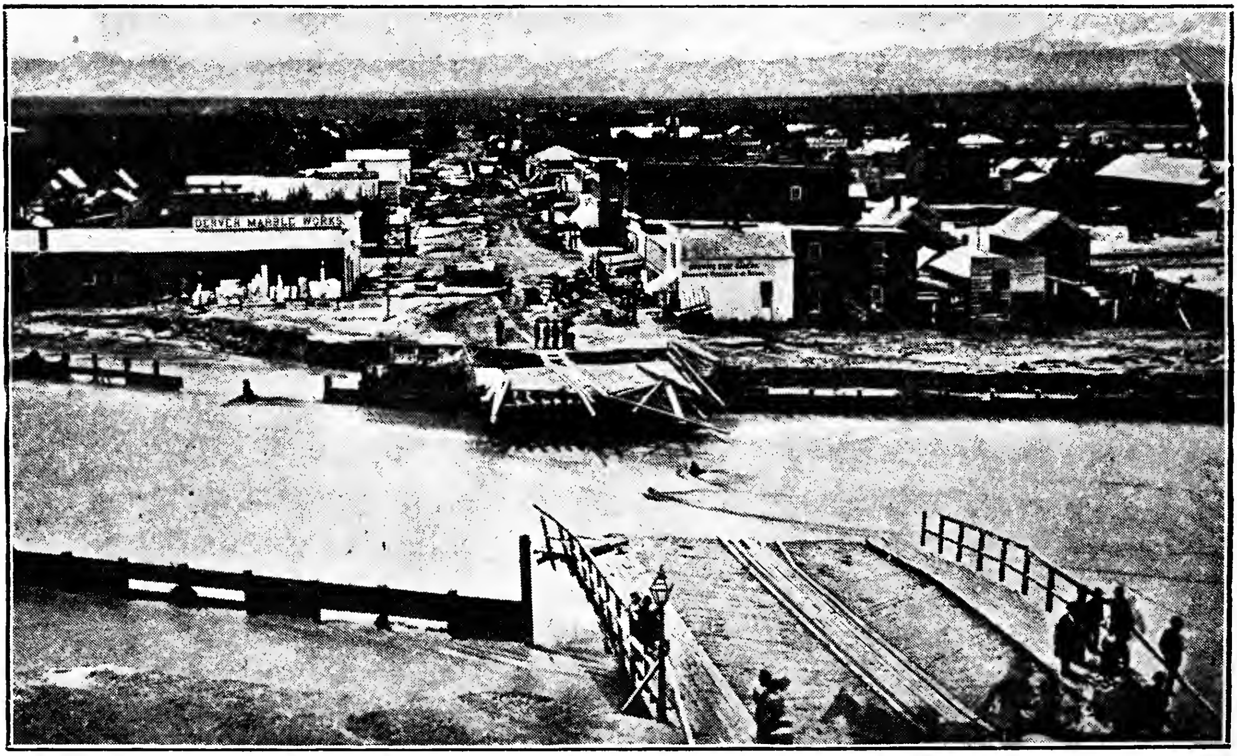
Respectfully submitted,

A. LINCOLN FELLOWS,
J. B. HUNTER,
C. A. TREASE,
Cherry Creek Flood Commission.

CHERRY CREEK FLOOD



LARIMER STREET, LOOKING WEST, MAY 20, 1864



LARIMER STREET, LOOKING WEST, MAY 22, 1878

Report of the Cherry Creek Flood Commission

INTRODUCTION

On July 14, 1912, a flood occurred in the Cherry Creek drainage basin within and above the city of Denver, which resulted in great damage to the city and adjacent territory, and again aroused the city officials and the various civic bodies to the necessity of preparing and adopting plans for the control of Cherry Creek floods. The fact has been generally recognized that floods as great as, or even of far greater magnitude than, that of July 14 may occur at any time in the Cherry Creek basin, and great apprehension has been felt on account of the possible danger.

Immediately after the occurrence of this flood the Boards of Supervisors and Aldermen were called together in joint session by His Honor, the Mayor, and a resolution was adopted, promising to support the Mayor in such measures as might seem to him to be necessary in providing for the welfare of the city. At this meeting the Mayor announced that it was his intention to appoint a commission to investigate the general subject of Cherry Creek floods, and to make such recommendations as might seem desirable, with a view to controlling future floods. On July 17, 1912, the day following this meeting, the Mayor appointed as members of the Cherry Creek Flood Commission Messrs. John B. Hunter, former city engineer; C. A. Trease, a member of the city engineer's staff; and, with them, City Engineer A. Lincoln Fellows, as member ex officio and chairman of the Commission. The Commission estimated that it would require five months' time, or the remainder of the year, and the expenditure of about $8,000, to prepare a report upon Cherry Creek flood conditions, and it was in accordance with this estimate that the work was undertaken.

From the date of the appointment of this Commission and until its discharge, its members were actively engaged in making a study of the general situation, directing surveys and examinations, reporting its findings to the Board of Public Works, and preparing for the compilation of a general report upon the subject. Upon November 30, however, the Commission was dis-

charged by the Board of Public Works, and upon February 7, 1913, the former members were directed to submit to Mr. E. B. Van de Greyn, consulting engineer of the Board of Public Works, all data in their possession. These instructions were duly followed, but upon March 17 the former members of the Cherry Creek Flood Commission were requested, in the following resolution, to submit to the Board a final report.

"WHEREAS, This Board on the 7th day of February, 1913, duly adopted a resolution in which the members of the Cherry Creek Flood Commission were requested and directed to forthwith submit to E. B. Van de Greyn, consulting engineer, all of the facts, data, estimates, sketches, and all memoranda which have been gathered and worked out in connection with, or by, the said Commission in any or all of its undertakings; and

"WHEREAS, This Board is aware of the fact that the period of service of the said Commission has expired; and

"WHEREAS, This Board is desirous of aiding the matter of obtaining full and complete data, memoranda, and all other information now in the hands of the members of the said Commission;

"*Resolved,* By the Board of Public Works of the City and County of Denver:

"(1) That the resolution adopted by this Board on the 7th day of February, 1913, be, and hereby is, rescinded.

"(2) That the members of the late Cherry Creek Flood Commission be, and hereby are, requested to submit to this Board a final report as soon as possible, embodying all of the facts, data, estimates, and sketches, with their recommendations in the premises."

The former members of the Commission, however, were not officially notified of such action until April 7, 1913, upon which day Mr. Seth B. Bradley, president of the Board of Public Works, personally notified Mr. Fellows of the action of the Board and requested him to proceed with the compilation of a report, with recommendations. On April 8, 1913, the Board of Public Works again officially reappointed the Cherry Creek Flood Commission, in the terms stated in the following resolution:

"WHEREAS, On July 17, 1912, John B. Hunter and C. A. Trease were duly appointed to act jointly with A. Lincoln Fellows, engineer of the Board of Public Works, as the Cherry Creek Flood Commission; and

"WHEREAS, On November 30, 1912, the services of the said the Cherry Creek Flood Commission were terminated by a resolution of this Board, the said resolution being in effect on the said November 30, 1912; and

"WHEREAS, By a resolution dated March 17, this Board requested the members of the late Cherry Creek Flood Commission to submit a final report as soon as possible, embodying all of the facts, data, estimates, and sketches, with their recommendations in the premises; and

"WHEREAS, It is deemed advisable that the said report, heretofore requested, should be official in its character and scope; therefore be it

"Resolved, By the Board of Public Works of the City and County of Denver:

"That the Cherry Creek Flood Commission be, and hereby is, reappointed, for the purpose of making its final official report; that the said appointment is without compensation, and that it is in effect forthwith."

In accordance with the request of the Board, the following report has been prepared:

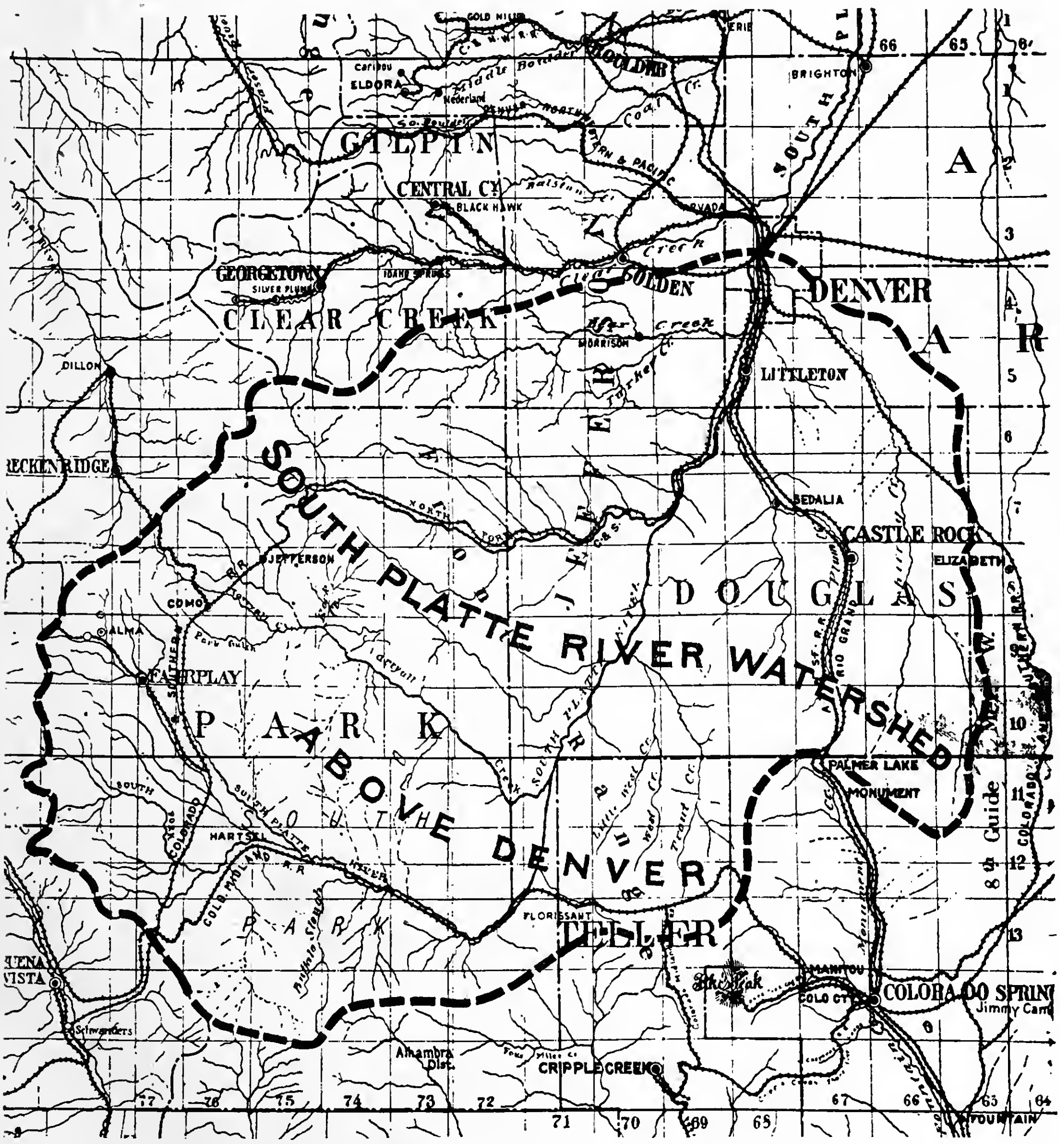
The Cherry Creek Flood Commission feels that it is due its members to say that it regrets that it has been impracticable, in view of the lack of moral and financial support, to make as complete and detailed a report as should be made, in view of the great importance of the subject. However, a number of surveys were made, and considerable detailed study was given to the general proposition of the control of Cherry Creek floods, and, through these studies, the Commission has arrived at definite conclusions and feels that it is in position to make specific recommendations. These conclusions and recommendations are based, for the most part, upon a careful study of the physical nature of the Cherry Creek water-shed, the precipitation records of the United States Weather Bureau, and the surveys and personal examinations of the territory in question, made by the members of the Commission, and employes of the city working under its direction.

The foregoing remarks are merely introductory, being intended to give a general idea as to the situation. In the following report the various features will be discussed more fully, as related to the main subjects under consideration—that of the control of future floods.

GENERAL PHYSICAL CONDITIONS

Denver, the capital city of the State of Colorado, is located in Township 3 South, Range 68 West, of the Sixth Principal Meridian, and other adjoining townships. It lies on both sides of the South Platte River, Cherry Creek entering the South Platte not far from the center of the city, at a point approximately identical with the crossing of the South Platte River by the Fourteenth Street viaduct. The water-shed area of the South Platte, with all its tributaries above the Fifteenth Street bridge, which is about 400 feet below the mouth of Cherry Creek in the city of Denver, is given by the United States Geological Survey as 3,840 square miles. The Cherry Creek water-shed area is, therefore, included in this amount. The Cherry Creek area is approximately 412 square miles, of which an area of 404 square miles is above the city limits; these amounts being obtained by measuring the drainage areas as shown on the atlas sheets of the Topographical Division of the United States Geological Survey. The Cherry Creek water-shed area is, therefore, only about 11 per cent of the total water-shed area discharging water through Denver, and it is obvious that a study of the Cherry Creek flood situation is a study of only a small portion of the entire problem. As typical of the conditions, attention is called particularly to the fact that Plum Creek enters the South Platte River about twelve miles above Denver. This tributary is very similar in its general character to Cherry Creek, although having a smaller drainage area. Bear Creek, Deer Creek, and other tributaries enter the river from the foothills, while the North and South Forks of the South Platte and numerous tributaries unite to form the mountain section of the river. It is clear that violent storms occurring on any portion of the 3,840 square miles of water-shed area above Denver will have greater or less effects at Denver, as they may come separately, or be combined with floods from other sections of the drainage basin; and these facts should have due consideration. The Cherry Creek Commission, however, on account of the shortness of time allotted it, the limited amount of funds at its disposal, and other conditions, has been able to give but a small amount of attention to any other parts of the drainage basin than the Cherry Creek area, and will be obliged to content itself with general conclusions only regarding the South Platte and its tributaries above Denver.

The city of Denver lies at an altitude varying from approximately 5,126 feet to 5,482 feet above sea-level. It is located in the so-called semi-arid region of the United States; irrigation being generally required for the production of satisfactory crops. This fact has an important bearing upon the character of the vegetation of the drainage area in general, particularly of that contained within the Cherry Creek water-shed. The physical characteristics of this water-shed will be discussed more fully in a subsequent division of this report.



FORMER FLOODS

The Cherry Creek flood of July 14, 1912, once more brought the people of the city of Denver face to face with a problem which had been raised periodically ever since the earliest settlement of the whites at the mouth of Cherry Creek. Even before that time the serious character of Cherry Creek floods was understood by the Indians, for we are informed that in the earliest days of what is now Denver the Indians warned the settlers that, if they persisted in building their homes in the Cherry Creek valley, they would some day be swept away by a great flood. As is now well known, this prophecy has been at least in part fulfilled in a number of instances, particularly in the floods of 1864, 1878, and 1912, and certain other floods of possibly somewhat less importance. Minor floods occur practically every year, but little attention has been paid to these since the construction of the Cherry Creek walls through the major portion of the city, and the consequent confining of the floods to a narrow channel. Careful research through the files of newspapers published in the city since its first settlement discloses the following floods of sufficient magnitude to attract public attention:

Thursday and Friday, May 19 and 20, 1864.
Tuesday, July 20, 1875.
Monday, May 22, 1876.
Wednesday, May 22, 1878.
Monday, July 20, 1885.
Sunday, July 26, 1885.
Friday, August 17, 1888.
Wednesday, August 4, 1897.
Friday, August 6, 1897.
Sunday, April 29, 1900.
Friday, August 11, 1911.
Sunday, June 9, 1912.
Sunday, July 14, 1912.

It appears desirable that the more important of these floods should be briefly discussed at this time, in order that the flood situation may be the better understood.

The first Cherry Creek flood of which we have any record occurred on Thursday and Friday, May 19 and 20, 1864. The flood reached its maximum height about 2 o'clock a. m., May 20. This height it maintained until about 7 a. m., at which time the waters began to recede. This flood had its origin at the upper

end of the Cherry Creek water-shed, being occasioned by a heavy fall of alternating hail and rain, occurring on the afternoon of May 19. This storm extended over the water-shed of Plum Creek also, which discharged into the South Platte River, making an unprecedented height. The two floods came together in Denver on the morning of the 20th, covering the lower portions of the city with water to a depth of from one to five feet, leaving great deposits of sand and gravel at different points, damaging property to the extent of several thousand dollars (a very serious matter to the city at that time), and drowning nineteen citizens. At that time a large portion of the city was constructed directly within and near the bed of Cherry Creek and the South Platte River bottoms. The water was about one foot in depth at the corner of the intersection of Fifteenth and Blake Streets. A vivid description from the pen of Professor A. J. Goldrick appeared in the *Commonwealth,* May 24, 1864, which description was also copied in the "Wilhelm Directory and History of Denver," now out of print.

The second Cherry Creek flood of which any record has been found occurred on Tuesday, July 20, 1875, and resulted directly from a five or six days' rain-storm. The creek began rising on the preceding Saturday, continuing to rise by fits and starts until the maximum flood stage was reached three days later. At this time an effort was made to turn the creek westerly, along or near Bayaud Avenue, to Lake Archer. Indeed, the City Council did, on November 24, adopt the plan of turning the creek from a point where Bayaud Avenue intersects Cherry Creek, and taking it thus westerly to Lake Archer, and a proposal was received for the construction of the same, the parties making the proposal agreeing to take part in cash and the balance in town lots, to be reclaimed from the old bed of Cherry Creek, in payment for their work. However, on the evening of November 27, 1875, the sheriff of Arapahoe County, in which the city of Denver was then located, served an injunction on the Mayor and the City Council, restraining them and each of them from executing any contract for the construction of a channel for turning, or attempting to turn, Cherry Creek, thus terminating this first attempt of this character.

The third Cherry Creek flood of record occurred on Monday, May 22, 1876. This flood resulted from a twenty-four-hour rain- and snow-storm, during which period of time 6.53 inches of pre-

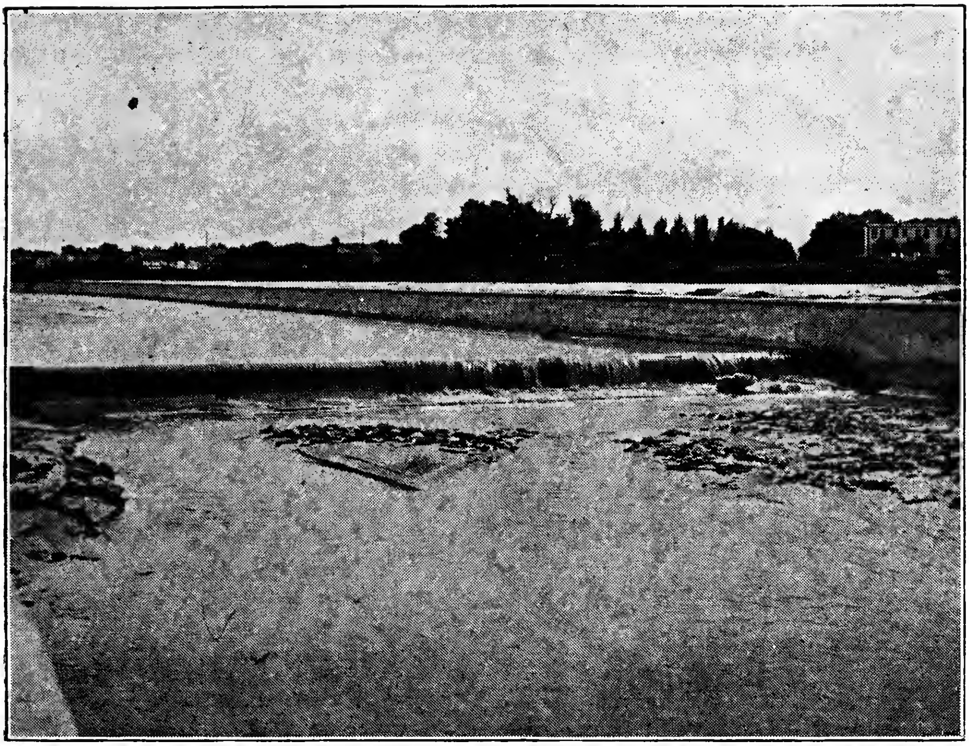
cipitation had fallen; this being the highest recorded by the United States Weather Bureau in Denver, whose records extend from 1872 to the present time. This flood would in all probability have been the greatest Cherry Creek flood known, had it not been for the fact that the snow and cold prevented a rapid running-off of the great amount of precipitation which had fallen. Throughout the afternoon and evening the banks of both Cherry Creek and South Platte River were lined with men, women, and children who waited, enduring the blinding storm of snow, standing ankle-deep in mud and slush, in anticipation of a flood of greater magnitude than that of 1864, both streams being then but little below the high-water mark of that flood. However, no great damage was done at that time.

The fourth Cherry Creek flood recorded occurred on the morning of Wednesday, May 22, 1878. It was considered by many of the earlier residents of Denver to be as large as the flood of 1864. We are not informed as to exactly where or how this one originated. The damage resulting therefrom was not nearly so great as that from the flood of 1864. The reasons for the decreased amount of damage appeared, however, to be due, not so much to any lesser flow of water, but rather to the facts that there were no buildings in the bed of the stream at the time of the 1878 flood; and, on the other hand, the channel of the creek was wider, deeper, and clearer than was the case at the time of the 1864 flood, and, furthermore, there appears to have been no especial flood in the South Platte River at this time, retarding the floow from Cherry Creek.

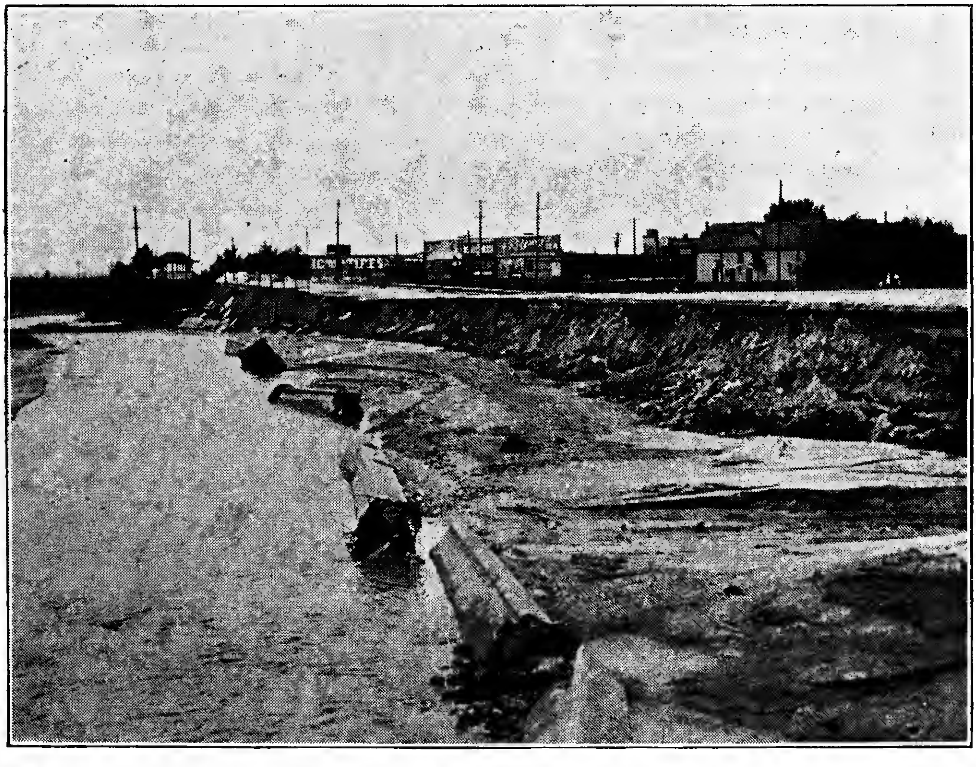
The fifth recorded Cherry Creek flood occurred on Monday, July 20, 1885. But little damage was done by this flood, and no detailed description is given thereof.

The sixth flood occurred on the afternoon of Sunday, July 26, 1885, and can be considered as at least the third largest flood in Cherry Creek, if not so large as those of 1878 and 1864. We are not informed as to just what part of the valley was covered by this storm, or whether it was from a general storm covering the drainage area as a whole. Considerable damage was done by this flood. West Denver was flooded about as it was in the flood of July 14, 1912. Mr. C. P. Allen, engineer of the Water Company, and Mr. E. S. Nettleton, State Engineer, estimated the discharge of this flood at its maximum to be 20,000 second-feet, the estimate being made at the Curtis Street bridge by timing floats and meas-

VIEWS OF CHERRY CREEK



OLD DAM AT SHERMAN STREET



EAST BANK AND SPEER BOULEVARD FROM SHERMAN STREET TO BROADWAY

uring the existing channel. All railroad bridges over Cherry Creek from Wynkoop Street to the Platte were washed away. Trains from the south loaded and unloaded their passengers at Sixth and Larimer Streets for several days.

The floods occurring between July 26, 1885, and July 14, 1912, were of relatively little importance, the channel being generally sufficiently large to furnish satisfactory waterway, so that but little damage was done.

The probabilities are that other floods have occurred in Cherry Creek that are not recorded in the foregoing list. The list is, however, sufficiently complete to give a fairly accurate idea as to the frequency and magnitude of the Cherry Creek floods.

THE FLOOD OF JULY 14, 1912

PRECIPITATION

About three o'clock, Sunday afternoon, July 14, 1912, a violent storm occurred in Denver, which lasted for about two hours. During that time 2.08 inches of water fell, and the wind reached a velocity of forty-eight miles an hour. The precipitation in twenty minutes of the period was 1.62 inches, and for five minutes was .87 inch. A part of the official record is as follows:

TABLE SHOWING RAINFALL

Time	Number of Inches	Time	Number of Minutes	Total Rainfall in Inches
3:25 to 3:30	.32	3:25 to 3:30	5	.32
3:30 to 3:35	.87	3:25 to 3:35	10	1.19
3:35 to 3:40	.33	3:25 to 3:40	15	1.52
3:40 to 3:45	.10	3:25 to 3:45	20	1.62
3:45 to 3:50	.05	3:25 to 3:50	25	1.67
3:50 to 3:55	.05	3:25 to 3:55	30	1.72

The main flood, however, was not due to the local precipitation in Denver. The run-off from the local storm occurred quickly, and by six o'clock there was little evidence of any flood in Cherry Creek. At 7:30 p. m. Cherry Creek was practically normal. About that time, however, the water began to rise in the bed of the creek, this water coming from the region some twenty miles above Denver, in the valley of Cherry Creek proper. As there are no Weather Bureau stations in the Cherry Creek valley above Denver, it is practically impossible to obtain exact data as to the amount of rainfall. Different people see the same storm from entirely different points of view. The average observer can give only a general idea as to the precipitation by making com-

parison between different storms, but he is usually unable to express himself in terms of rainfall in inches or any other definite units. Above Parker, twenty-three miles from the Union Depot at Denver, the rain was termed a hard rain, but was not judged by observers as a cloudburst. The general opinion seemed to be that there are usually rains, one or more times each year, practically as severe as was the one of July 14. The rain was, however, more general than usual, and of sufficient intensity to cause most of the tributaries to run bank-full and cause the main stream to overflow its banks in many places. The rain on Willow Creek water-shed, a tributary of Cherry Creek, was so heavy that the flood destroyed the dam of the Barney Baird Reservoir No. 3. This occurred at about 3:30 in the afternoon. The amount of water contained in this reservoir, however, is small, probably not exceeding ten acre-feet. This break occurred shortly after the heaviest rain and the greatest discharge, and consequent damage in this section of the valley was due to the breaking of this reservoir. The best cross-section of the stream above Parker is at the Montgomery bridge. The water at this point was then within about one foot of the floor of the bridge, thus giving a water area of 960 square feet. The discharge of the stream at this point, using the Kutter formula with $n = .030$, is 14,500 cubic feet per second.

The heaviest rainfall in the drainage area seems to have occurred in the section from Parker to a point about five miles to the north, or toward Denver. The rain was so intermingled with hail, and came down so fast, that it was said to be difficult to see a hundred yards. This rain was characterized by the citizens of that section as a cloudburst, and was said to have been the worst ever seen in that region. As nearly as can be computed from the high-water marks and the rate of fall of the stream, the discharge seemed to be about 27,400 cubic feet per second at the maximum stage. This estimate is probably high.

There was thought to be less rain in the section extending from a point five miles north of Parker to the city of Denver than in the section above, but by many people residing in this section it was classed as a cloudburst. There was very little hail in this section. Using the same data as those used in the sections above, the amount of water discharged by the stream at the maximum stage appeared to be about 30,000 second-feet.

The stream is fed on both sides by numerous tributaries of variable sizes. Owing to the difficulty of obtaining reliable infor-

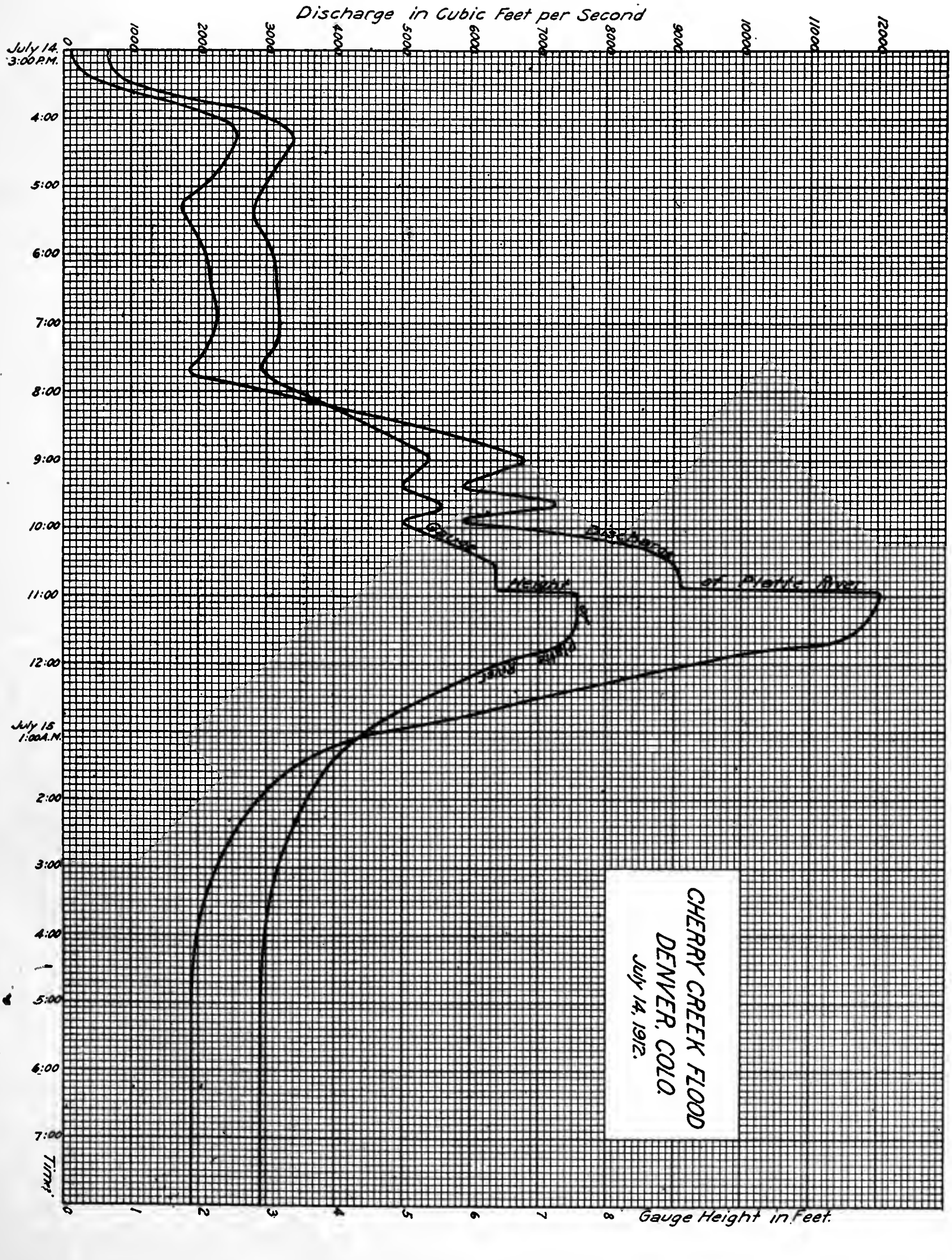
mation concerning the capacity of the various tributaries, only a few of the more important are mentioned. Willow Creek, which is below Franktown, contributed largely to the flood on account of the reservoir which broke a short distance above the junction with Cherry Creek. Newlin's Gulch at Parker, containing thirty to forty square miles of territory, also contributed largely to the water of the stream. Sampson's Gulch, about eight miles below Parker, also furnished a large amount of water contributing to the high-water stage. Among the other more or less important gulches are Smith's, Happy Canyon, Gibson, Wilson, and Lemon Gulches. The storm apparently traveled in a northwesterly direction and was very general, covering the entire water-shed of Cherry Creek valley, but with varying degrees of intensity. The rain was heaviest at Franktown, about 2:30 p. m., continuing steadily for several hours. Between Franktown and Parker the storm was at its maximum from 3 to 4 p. m., practically at the same time as at Denver. Below Parker the maximum was reached from 4 to 4:20 p. m., thus showing that this storm followed the trend of the creek to a certain extent. Cherry Creek is fed by a large number of tributaries, which during the greater portion of the year are dry gulches. They have drainage areas varying from a very few square miles to forty or fifty square miles in extent. During a storm of considerable length and over a large area, these dry gulches rise almost immediately, and the water comes with great velocity, causing considerable erosion and heavy damage. It appears that during this particular storm every tributary of this section was carrying practically its maximum amount of water. The storm appeared to travel down the creek at approximately the same rate that the water in the channel did, thus giving the most severe conditions at every point.

The precipitation, however, appears in general to have been much less on the head-waters of the stream, and through a great portion of its length, than may be expected as reasonably possible on similar occasions. It appears that the maximum precipitation occurred at a point about twenty miles above Denver, and it is also reasonably probable that the maximum flood discharge came from an area of approximately from sixty to one hundred square miles. Above Castlewood reservoir, about thirty-five miles above Denver, there seems to have been but little precipitation, the total effect of the rainfall of July 14 and 15 raising the water in this reservoir only three feet, indicating something less than 500 acre-

feet as the total run-off of the drainage area above the reservoir. As the drainage area above Castlewood reservoir is estimated as being equal to about 175 miles, it appears, therefore, that certainly all of the flood came from an area of less than 200 square miles, and the indications are that by far the major portion of the flood came from an area not exceeding 100 square miles in extent.

FLOOD DISCHARGE

The amount of water discharged as the result of the flood has been variously estimated by different observers. As the maximum



stage of the flood passed through Denver about 10 p. m., it was, of course, difficult for even approximate measurements to be made. A certain amount of information is available, however, resulting from observations that may be classed under three different headings, viz.: (1) discharge at Sixteenth Street gauging station on South Platte River; (2) estimates made by different hydrographic engineers during the time of the passing of the flood; (3) estimates of discharge based on maximum flood sections and grades of channel, using the Kutter formula, with $n = .030$.

Discharge at Sixteenth Street Gauging Station on South Platte River.—This gauging station is maintained by the office of the State Engineer of Colorado, and the following report concerning the discharge is taken from a paper entitled "The Cherry Creek Flood, Denver, Colorado," by Charles W. Comstock, State Engineer of Colorado, published in *Engineering News,* Volume LXVIII, No. 7, August 15, 1912:

"Figure 1 shows the curve of rainfall at Denver for the three hours of the storm, and also the curves of gauge heights and discharges of the South Platte River at a point about 1,000 feet below the mouth of Cherry Creek, for the same period. The discharges are estimated from an extension of the rating curve for the river channel at this point and are liable to important errors from two causes—first, because the flood wave was very short; second, because the unprecedented high water must have materially altered the channel.

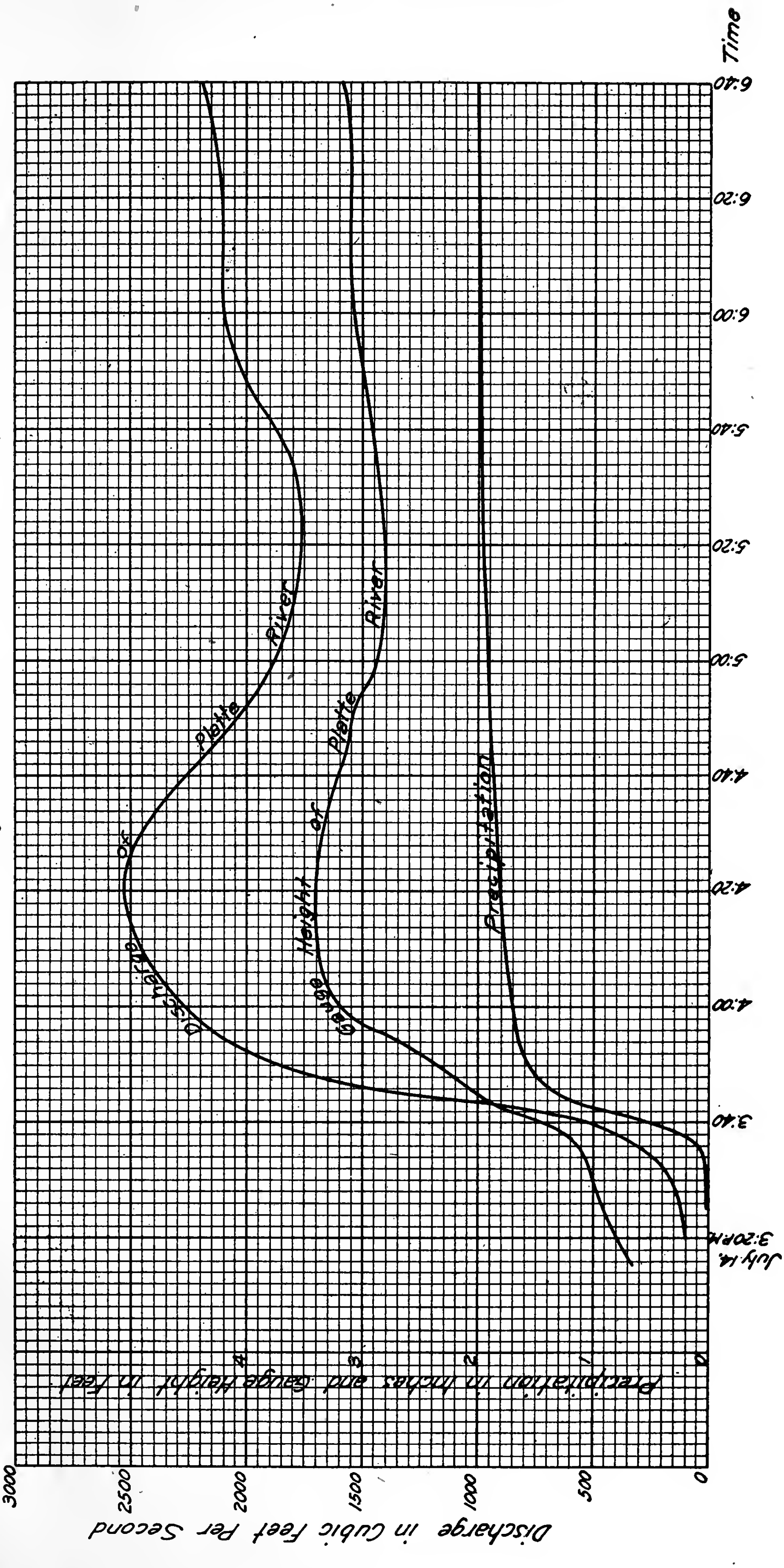
"The following table of discharge measurements shows the changes which occurred during and after the high-water period:

TABLE OF DISCHARGE MEASUREMENTS

Date 1912	Area of Section Sq. Ft.	Mean Velocity Ft. per Sec.	Gauge Height	Discharge Cu. Ft. per Second
July 1	439	4.31	2.95	1,893
July 8	216	2.48	1.32	536
July 15	448	4.28	2.88	1,915
July 26	326	4.99	1.25	1,628

"The measurements on July 15, the day following the flood, show that there was no important permanent change in the channel, although it is not improbable that it was scoured out during extreme high water and filled in again as the river fell. Between the 15th and the 26th a very decided change occurred. For the same gauge height the area of the section increased by 50 per cent, and the mean velocity doubled, thus multiplying the discharge by three. This is readily explainable by known changes in the river channel. For many years a low dam, built to divert

CHERRY CREEK FLOOD
DENVER, COLO.
July 14, 1912.



water into the Farmers' and Gardeners' Ditch, has existed in the South Platte River about a quarter of a mile below the gauging station. This produced some back water, decreasing the slope of the water surface and thus the velocity. The dam was destroyed by the flood, and the unusual discharge of the next few days cleared out the river channel and increased the surface slope.

"Figure 2 shows the curves of gauge heights and discharges of the South Platte River at the Denver gauging station for the afternoon and night of July 14. The maximum discharge of 12,000 cubic feet per second shown by this diagram has been objected to by some local engineers as probably too great. On the other hand, one experienced hydrographer who observed the progress of the flood with great care has estimated the maximum discharge at 14,000 cubic feet per second.

"It will be noted that during the first three hours the rise in the river followed very closely the local precipitation. When we consider the large area of street pavements, house roofs, and other impermeable surfaces, this result is to be expected. Following the period of excessive rainfall there was a slight fall in the river, after which the discharge remained nearly constant for three hours. In the next hour the river rose 2.50 feet. This probably marks the arrival of the run-off from the excessive rains which fell some twenty miles above Denver in the Cherry Creek valley. Following some oscillations of about one-half foot, the gauge rose rapidly to 6.40, where it remained for a few minutes, and then shot up to 7.60, indicating an almost instantaneous increase in discharge of 3,000 cubic feet per second. This abrupt rise was due to the failure of a pile bridge across Cherry Creek about four miles from its mouth. During the early hours of the flood, large quantities of drift floated down the creek and lodged against the bridge, backing up a large volume of water in the low lands above. This was suddenly released by the bridge failure shortly before 11 o'clock, with the result shown on the diagram.

"Had it not been for the temporary backing-up of the Cherry Creek water by the bridge at York Street, it is probable that the maximum discharge of the river would not have exceeded 10,000 cubic feet per second. If it be assumed that 1,000 cubic feet per second came from the South Platte exclusive of Cherry Creek, the latter supplied 9,000 cubic feet per second, or 21 cubic feet per second per square mile of drainage area.

"The total discharge of the South Platte River at Denver between 3 o'clock p. m., July 14, and 6 o'clock a. m., July 15, was

5,000 acre-feet. Of this about 3,800 acre-feet came from Cherry Creek. This is 17 acre-feet per square mile of the drainage area below Castlewood dam. The maximum rate of flow was 40 cubic feet per second per square mile of that area."

Commenting upon this estimate, it will be observed that Mr. Comstock makes reference to two elements of doubt, viz.: (1) the shortness of the flood wave, and (2) the fact that the unprecedented high water must have materially altered the channel. Any errors existing on account of these elements of doubt would have a tendency to show a less amount than was actually flowing. It is known, also, that a large amount of water spread out over different parts of the city, and that at least a considerable portion of water emptied into the South Platte below the gauging station. The first of these conditions necessarily resulted in extending the period of discharge over a greater length of time than would have been the case had it been possible for the water to come down all at once. The second condition would clearly indicate that the amount of water passing the gauging station did not show the total amount coming down the creek. All the elements of doubt, therefore, are in favor of a larger maximum flow than the records of the gauging station would seem to indicate. How much larger the flow might have been, had it not been restricted, it is impossible to state with any degree of certainty.

Estimates Made by Different Hydrographic Engineers During the Time of the Passing of the Flood.—A number of estimates of the amount of water flowing along Cherry Creek were made by hydraulic engineers well qualified to judge. These generally agree within reasonable limits when the difficulties of making the estimates are taken into consideration. Of these the most detailed was made by Mr. W. B. Freeman, hydraulic engineer, who for a number of years has been located at Denver as the resident hydrographic engineer of the United States Geological Survey. Mr. Freeman published an article in the daily *Rocky Mountain News* of July 17, 1912, an extract from which is given herewith, as follows:

"It so happened that I was on the ground Sunday night shortly after the stream was at its maximum height, and I was able to obtain data from which to make fair estimates of the actual discharge. Just below the Bannock Street bridge, about 200 yards down stream from the Broadway Street bridge, the

creek was practically confined to one channel, so I took my sections there. As is well known, the creek overflowed its banks at most places along its course; therefore I was fortunate in being able to find a place where it was within its banks.

"Eight Feet above Stream-Bed

"This does not mean within the channel bounded by the retaining wall, the top of which, at the point where my measurements were taken, was eight feet above the stream-bed.

"The flood was caused by the heavy rainfall within the basin of Cherry Creek, beginning about 3:30 Sunday afternoon. I believe there was an insignificant rise of the stream shortly afterwards—at least there was a two and one-half foot rise in the Platte River about 4 p. m. At 8 p. m. there was only a small flow in Cherry Creek, but the creek commenced to rise rapidly a short time afterwards, and about 10 p. m. it reached a maximum depth of eleven feet near the Bannock Street bridge. From that time it fell rapidly; at midnight it had fallen to a depth of perhaps three feet.

"Creek Fell Gradually

"At 8 a. m. the depth was two feet, and at 11 a. m. it was 1.9 feet. It continued to fall gradually during the day, and at 8 a. m. Tuesday it was one foot lower than on the preceding morning, and the discharge was estimated to be less than seventy cubic feet a second.

"The State Engineer has an automatic water stage register on the Platte River at the Sixteenth Street viaduct, a few hundred feet below the mouth of Cherry Creek, and a study of the register chart, which accompanies this report, will give a fair idea of the rise and fall of Cherry Creek. The river was no doubt affected to some extent by flood waters coming in from tributaries above the mouth of Cherry Creek, but the latter stream was by far the greatest contributing element at the time it was near its maximum.

"Platte Rose to 3.50 Feet

"As will be seen by reference to the chart, the Platte River rose from a stationary stage of about one foot at 3:30 on Sunday afternoon to about 3.50 feet at 4:30 p. m., after which it went rather suddenly to a height of more than five feet, and from 10 to 11 p. m. it rose rapidly to a maximum gauge height of 7.60. From

that time it fell rapidly to a gauge height of three feet at 4 a. m., and then dropped gradually.

"The chart of the Platte River conforms quite closely with the description I have given of the Cherry Creek flood at the Bannock Street bridge, except that the maximum gauge height occurred about one hour later on the Platte River, for the reason that the flood waters of Cherry Creek were very much impeded by numerous bridges and other obstructions near the mouth of that stream.

"Took Float Observations

"At 12:30 Monday morning I took some float observations of velocity over a 300-foot float course below the Bannock Street bridge. At that time the depth of the water was about six feet, and the waterway was not obstructed in any way at that place by bridges or debris. A couple of hours before there had been a considerable piling-up of drift above the bridge, owing to the inadequacy of area-way provided, though the conditions at the Bannock Street bridge had been much better than at most of the bridges along the creek.

"My measurements at a depth of six feet showed a surface velocity of almost exactly ten feet per second over a course obstructed only by the small concrete weirs at intervals across the stream-bed. When the depth had diminished to two feet, the observed velocity was three feet per second. From these observations and such other information as I was able to collect, and from a cross-section of the stream taken on the morning of July 15, I have made what I consider fair estimates of the discharge.

"Flowed over Left Bank

"The cross-section, which is given herewith, was taken about fifty feet down-stream from the Bannock Street bridge and about 300 feet up-stream from a concrete weir. At this section the stream at its maximum height did not overflow either bank, though it went over the left bank to a depth of from one to two feet a couple of hundred feet below.

"The greatest depth was 11.2 feet, and at that stage the water was 3.2 feet over the top of the retaining wall. The area of the flood section was 920 square feet and the estimated maximum discharge was 11,000 second-feet. At a depth of eight feet, when the water was just level with the top of the retaining wall, the area of the cross-section was 610 square feet and the estimated discharge was 6,400 second-feet. This was more than the maxi-

mum which the channel within the retaining walls seems capable of carrying because of the weirs across the stream.

"Waterway Inadequate

"The measured height of the top of the retaining wall above the crest of these weirs is only 5.70 feet, and since the width of the channel is only eighty feet, the effective area of cross-section at the weirs is about 450 feet, and the absolute maximum capacity cannot exceed 5,500 second-feet. It will be noticed that this is only half the estimated maximum discharge on the night of July 14, and it is unfortunate that a waterway built at so large a cost to the city should have been designed with such an inadequate area of cross-section.

"Levels were taken of the flood height of the stream at one of the weirs, and it was found that at the highest stages, as indicated by the drift, the water went about one foot higher, above the top of the retaining wall just below the weir, than at any other place. The same condition was noticed at every weir for a long distance; so there is no question that they present a material obstruction to the free flow of the stream, despite the fact that sand and silt have been deposited behind them almost up to the level of the crest.

"Sudden Rush Causes Damage

"The estimated flow of Cherry Creek at 11 a. m., July 15, was 360 second-feet, and at 8 a. m., July 16, it had fallen to a discharge of about 60 second-feet.

"The total run-off during this flood was not as great as might be imagined. The damage was caused by the sudden rush of flood waters. Had the flood been uniformly distributed over twelve hours, it would have very likely gone by without any serious consequence.

"My estimate of the total run-off during the twelve-hour period from 8 p. m., July 14, to 8 a. m., July 15, is four thousand (4,000) acre-feet, or sufficient water to cover four thousand acres one foot in depth. It is about the amount of water required in the vicinity of Denver to irrigate two thousand (2,000) acres during one irrigation season.

"Total Run-off 4,400 Feet

"The discharge for the twenty-four-hour period from 8 a. m., July 15, to 8 a. m., July 16, is estimated to be about four hundred (400) acre-feet; so that the total run-off was about four thousand four hundred (4,400) acre-feet from this one storm.

"The Platte River rose from a discharge of about one hundred (100) second-feet at 3 p. m., July 14, to an estimated maximum of thirteen thousand (13,000) second-feet at 11 p. m. At that time the gauge height was 7.60 feet and the area of cross-section about 1,400 square feet. It fell rapidly to a discharge of about two thousand (2,000) second-feet at 4 a. m., July 15. It is estimated that the total run-off between 8 p. m., July 14, and 8 a. m., July 15, was five thousand (5,000) acre-feet.

"Storm Area Not Known

"It is not known how large an area in the water-shed of Cherry Creek was affected by the storm. So far I have had access only to the rainfall records at Denver. It is understood that there was a large precipitation on July 14 at Castle Rock, which is some twenty miles below the upper end of the Cherry Creek basin, which is more than fifty miles in length. The rainfall at Colorado Springs, some distance south of the Cherry Creek drainage, was 1.09 inches during the storm of July 14, and the total at Denver was 2.08 inches.

"The rate of the precipitation at Denver was very high and is said to be almost unprecedented in this locality. During one five minutes of the storm Sunday afternoon nearly three-fourths inches fell, and more than one inch in ten minutes. The total rainfall for one hour, from 3:30 to 4:30, was 1.58 inches.

"It is hardly likely that such an excessive rate of rainfall occurred over a very large area—that is, in excess of 100 square miles.

"Area of 445 Square Miles

"The drainage area of Cherry Creek above Castlewood dam is 200 square miles, and above Denver it is 445 square miles, as planimetered from the topographic sheets of the United States Geological Survey.

"A maximum discharge of 11,000 second-feet at Denver would be equivalent to a rate of run-off of nearly twenty-five second-feet per square mile for the whole water-shed above Denver, and to fifty second-feet per square mile if only half the water-shed was affected by the storm. I am inclined to think that the latter premise is more nearly correct.

"If the rainfall which caused this flood was as much as two inches over the whole water-shed, it would mean that every square mile contributed just ten second-feet to the total run-off, or the run-off depth over the basin was about two-tenths of an inch. In

other words, the relation of the run-off to rainfall was only 10 per cent.

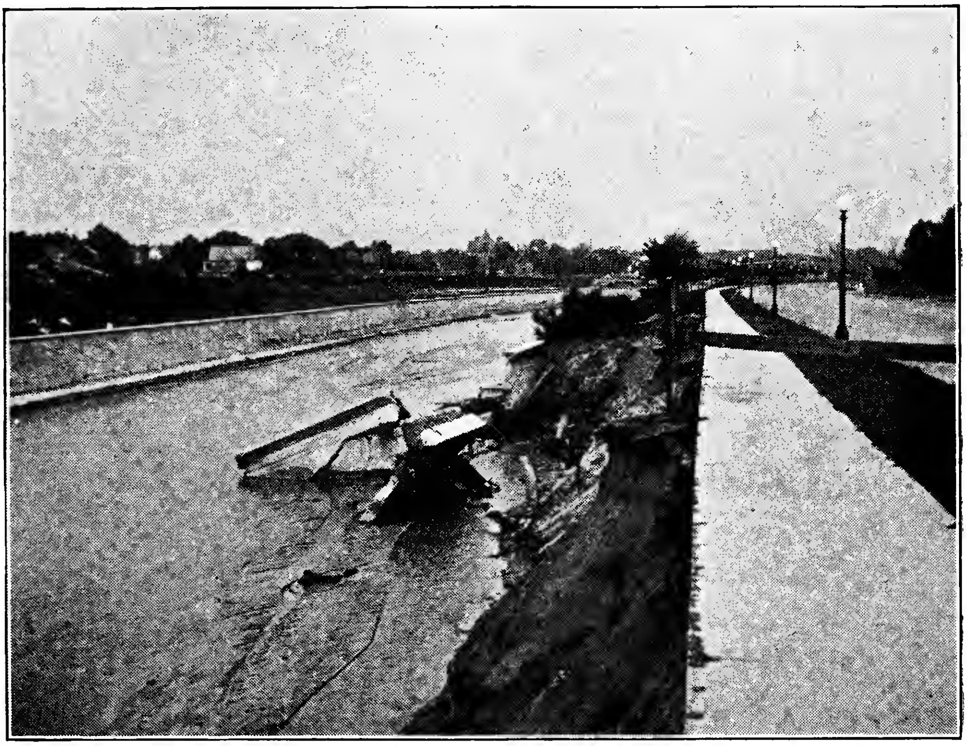
"Value Much Too Low

"Such a value is unquestionably very much too low, and I doubt very much if it was less than 25 or 30 per cent, where the intensity of the rainfall was as great as it was at Denver. I think that I am safe in saying that the rainfall over the water-shed did not average more than one inch and that the run-off was 20 per cent. If the rainfall averaged one and one-half inches over one-half the water-shed, the depth of run-off was nearly four-tenths of an inch and the rate of run-off 25 per cent, which I am inclined to believe represents the actual conditions more closely."

It is practically impossible to estimate what corrections, if any, should be made to the estimates made by Mr. Freeman and others. On the one hand, it is extremely probable, and even reasonably certain, that the flood period was considerably longer in Denver at the point where the measurements were made by Mr. Freeman than was the case above the city limits. It is known that the water spread out over a considerable area throughout very large portions of the Cherry Creek valley, being retarded by bridges, shallow channels, diversion dams for irrigation canals, etc. On the other hand, it is known that the York Street bridge in Denver acted as a dam for a short space of time, raising the water above this point, and that, when this dam broke, the water in the channel below naturally rose to a greater height than before the giving-way of the bridge. On the whole, however, the Commission believes that the probabilities are in favor of a much higher maximum discharge above the city limits than is shown at any point below Broadway. This opinion seems to be warranted by the estimates made of the flow of water above the city limits, as determined by the third method herein discussed.

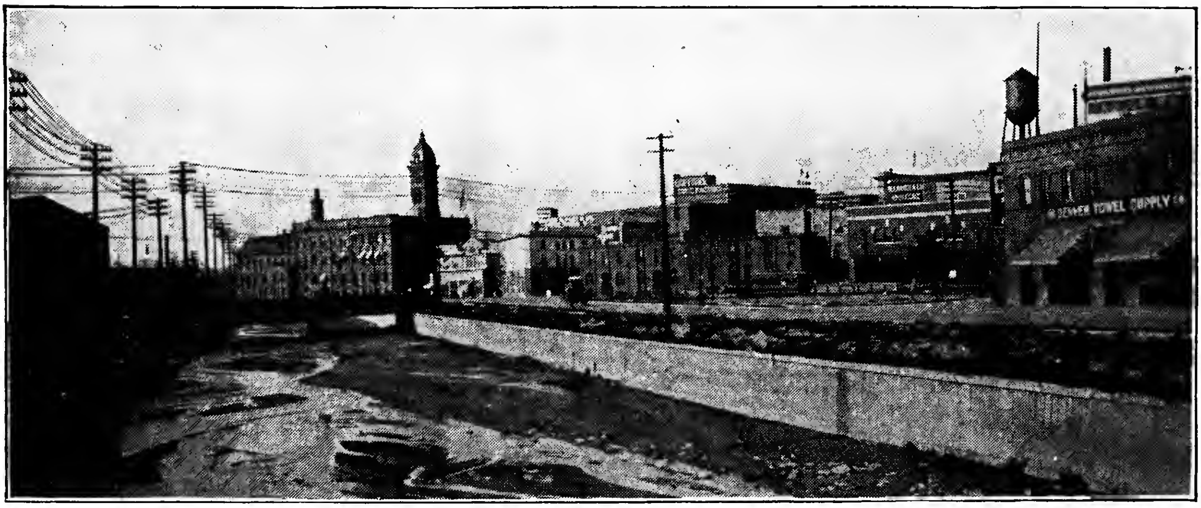
Estimate of Discharge.—A number of estimates of the flow of water in Cherry Creek, as shown by the high-water marks, taking the grade of the channel as determined by taking levels along its course and using the Kutter formula with $n = .030$, were made by different engineers connected with the city Engineering Department. These estimates were made at a number of different points, extending between the city limits and a point about thirty miles above the city. If we can assume that these estimates were based upon correct premises, the conclusion that a maximum stage of at least 25,000 cubic feet per second was

VIEWS OF CHERRY CREEK AFTER FLOOD OF JULY 14, 1912



NORTH BANK FROM DOWNING TO CORONA

NORTH BANK AT FIRST AVENUE FROM LAFAYETTE TO DOWNING



VIEWS OF CHERRY CREEK, SHOWING ACTUAL CONDITION OF CHANNEL BEFORE AND AFTER CONSTRUCTION OF WALLS—TAKEN FROM CURTIS STREET BRIDGE

reached a short distance above the city will be inevitable. That such a discharge was possible is well within the bounds of reason, as will be shown hereafter. That it may possibly have occurred at this time is reasonable also, as it is certain that the actual volume of water in acre-feet was relatively small, and a small amount of spreading-out of the water for temporary storage at different points in the valley would have acted to a certain extent as a method of regulating the flow, and would thus have resulted in a considerably diminished flow through the city.

The Commission concludes, in view of all the considerations, that the actual maximum discharge of Cherry Creek was somewhat larger than is indicated by the gauging station records, as shown in Method No. 1; that the maximum discharge at the Bannock Street bridge was approximately as shown by Mr. Freeman in the second method, although perhaps somewhat larger; and that the maximum discharge at any point on the creek above the city limits may have reached as high an amount as 25,000 cubic feet per second.

DAMAGES RESULTING FROM THE FLOOD

As is usually the case on similar occasions, the estimates made immediately after the flood grossly exaggerated the extent of the volume of the flood and the consequent damages. Thus the *Denver Republican* of July 15, 1912, gives an estimate of the loss to the city of between $250,000 and $500,000, and to private individuals and corporations of $1,500,000. It is uncertain as to what proportion of the estimated damages should be charged against the Cherry Creek flood itself, and how much against the washing of streets, breaking of sewers, and other damages resulting from the local storm, but not due, in any degree, to the discharge of Cherry Creek. In any case, however, this estimate appears to have been greatly exaggerated, and the reports that were published in other parts of the country were even more grossly exaggerated. Throughout the civilized world the general impression was given out that Denver was practically destroyed, only those upon the mountain-sides escaping with their lives. As a matter of fact, the damages, as compared with recent floods in other parts of the country, are almost insignificant. Probably all monetary damages could have been made good at a cost of not to exceed $50,000 to the city, and from $250,000 to $500,000 to the public generally. But little damage was done to the public-utility corporations, and the interruptions of water, gas, elec-

tricity, telephone, and tramway services were slight and of brief duration. The greater part of the financial loss fell upon merchants and warehouse-owners who had stocks of goods stored in basements of buildings near Cherry Creek. Suits were brought against the city by such parties, claiming damages to the extent of approximately $250,000; and how many more suits might have been brought, had the plaintiffs been successful in securing payment of the damages claimed, is altogether uncertain. Fortunately for the city, however, Judge Perry, before whom the case was brought, decided that the city was not responsible for the damage caused by the flood.

A more detailed statement connected with this suit is given in the appendix attached hereto. Only two lives were lost. Both of these unfortunate individuals were poor people who lived on low ground near the river, and in both cases they were incapacitated, by reason of sickness, from making their escape. All who applied for assistance were taken care of by the city and through subscriptions obtained within the city, and within two or three days of the occurrence of the flood practically all parts of the city were again under nearly normal conditions.

The principal causes for damage within the city limits may be grouped as follows:

1. The Farmers' and Gardeners' Canal Dam.

2. The character of the bridges on South Platte River and lower Cherry Creek.

3. The fact that the lower part of Cherry Creek had never been walled and cleaned.

4. The fact that the bed of Cherry Creek had been used to a considerable extent as a dumping-ground.

5. The fact that construction work of walls was under way in the vicinity of the Market Street and Blake Street bridges.

6. The weirs along the channel of Cherry Creek constructed for ornamental purposes.

7. The fact that the channel of Cherry Creek above Downing Street is unwalled.

8. The existence of pile bridges at York Street, Steele Street, and Colorado Boulevard, and at a number of places above the city limits.

9. The vast amount of drift, composed of trees, logs, buildings, bridge timbers, etc., that came down the creek at the time of the flood.

All of these causes will be discussed as briefly as possible.

1. *Farmers' and Gardeners' Dam.*—The Farmers' and Gardeners' ditch belongs to the city, and furnishes water for what is known as the old Poor Farm, and also for a number of Italian gardeners, and also that which is used by the American Smelting and Refining Company, for condensing purposes at the Globe Smelter, just north of the northern boundary of the city. Originally water was taken from the river without the aid of any diversion dam of importance, but about the year 1897, owing to the scouring of the channel of the South Platte, the head of the ditch was extended for a short distance, and a diversion dam was built across the channel of the South Platte just above the Nineteenth Street bridge. This diversion dam is approximately 2,000 feet below the mouth of Cherry Creek, but it was thought that the bed of the South Platte was raised at the mouth of Cherry Creek approximately five feet—certainly three or four feet. This dam has long been recognized as a source of danger to the city, for the reason that the beds of South Platte and of Cherry Creek near its mouth were so raised that the discharge of Cherry Creek through the lower part of its course was materially decreased. One of the results of the flood was the breaking of this dam, and the Flood Commission advised against replacing it; consequently the Farmers' and Gardeners' ditch has been extended up-stream, by means of a concrete conduit, to a point just above the mouth of Cherry Creek, and the entire dam has been removed.

2. *Bridges.*—This subject will be treated more in detail in connection with the report of the work of the Flood Commission. The fact is to be noted here, however, that one of the sources of danger was the existence of bridges, some belonging to the city and some belonging to railroad companies, with insufficient waterways, due either to the fact that they were constructed on piles, or with not sufficient elevation above the stream-bed. This deficiency was particularly marked in the case of two of the railroad pile bridges on South Platte River about Twentieth Street, and two railroad pile bridges and one pile bridge belonging to the city, across Cherry Creek between Wazee Street and the mouth of the creek. Even in a flood of moderate size enough drift is frequently brought down to convert these bridges into dams, the logs and other debris lodging against the piles. In the case of the flood of July 14, 1912, the drift formed veritable beaver dams against some of these bridges, almost entirely checking the flow of water under

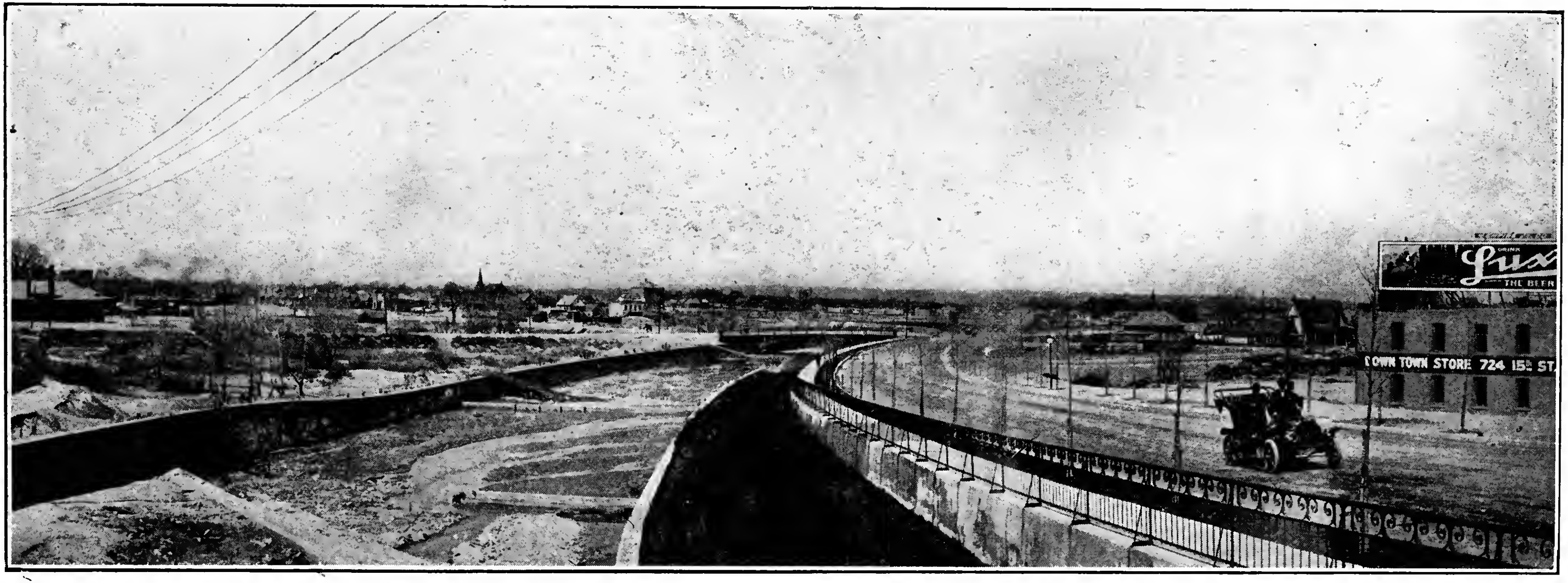
them, although a vast amount had been caught on bridges above or been carried off over the lower grounds of the city. The Commission advised that all of these pile and low bridges be replaced by higher structures, giving waterways as clear and free of obstruction as possible.

3. *The Fact that the Lower Part of Cherry Creek Had Never Been Walled and Cleaned.*—During the past few years walls have been built along both sides of Cherry Creek from Downing Street to Blake Street. Unfortunately, however, no walls have been constructed below Blake Street up to the present time, although this would seem to have been the more logical section of the stream at which to commence the work. This matter is discussed more fully elsewhere, but attention is called to the conditions at this time, as the stream-bed was in such a condition that it could probably carry not more than half the water that the walled section of the channel could carry, even in spite of the weirs referred to later.

4. *Dumping.*—Remarkable as it may appear, the channel of Cherry Creek from Blake Street to the mouth of the river had been used for a number of years as a dumping-ground, both by officials of the city and by parties owning land along the channel. This use of the channel had narrowed the water-course to such an extent, in spite of the erosion caused by the small floods occurring from time to time, that the capacity of the stream was much less than it otherwise would have been. It is probably a fact that the channel at the time of the occurrence of the flood of July 14 could carry much more water than it could have carried at any preceding great flood; but, had it not been for the use to which the channel had been subjected, it could certainly have carried much more water than was possible for it to convey under the conditions.

5. *Construction Work under Way.*—The work of walling the creek was under way in the vicinity of the City Hall from Lawrence Street to Blake Street, and the material excavated from the trenches where the foundations of the walls were to be constructed was lying in the bed of the stream above the Blake Street bridge. The material under the Blake Street bridge, moreover, had not as yet been removed; consequently the waterway under the Blake Street bridge was blocked to a much greater extent than would have been the case had the flood not occurred until a few weeks later.

TAKEN FROM BROADWAY BRIDGE, LOOKING SOUTHEAST, BEFORE CONSTRUCTION OF WALLS



TAKEN FROM BROADWAY BRIDGE, LOOKING NORTHWEST, AFTER CONSTRUCTION OF WALLS

6. *Weirs.*—A number of weirs had been constructed along the bed of Cherry Creek between the retaining walls, for the purpose of forming ornamental pools. These weirs resulted in making the bed of Cherry Creek from two and one-half to three feet higher than it would otherwise have been, thus decreasing the carrying capacity of the channel between one-third and one-half. It was noticeable at the time of the occurrence of the flood of July 14, 1912, that where damage was done to the walls above Market Street, it was generally clearly due to the existence of these weirs.

7. *Unwalled Channel.*—The channel of Cherry Creek is walled only as far up as Downing Street; consequently, owing to the fact that the channel is not contracted, as below, there has been little scouring, and the channel above Downing Street is frequently several hundred feet in width and of shallow depth. As a result, at the time of the occurrence of such a flood as that of July 14 the water overflows the banks, as was the case in this instance, in the vicinity of the Country Club grounds, and above that locality. Thus much more drift and sand of various kinds were brought down than would otherwise have been the case.

8. *Pile Bridges.*—All of the bridges across Cherry Creek, both within the city of Denver above Downing Street and above the city limits, with one exception, rest on piles, and all of these pile bridges went out. Probably in each case a dam of more or less importance was first created through the lodging of driftwood, etc. These dams gave way, taking the bridges with them. This is known to have been the case at the York Street bridge, where the dam was of considerable size, and the amount of water retained by it must have been very considerable; consequently, when this dam gave way, which occurred about 10 o'clock p. m., the water below rose rapidly and resulted in much greater damages than would otherwise have been the case.

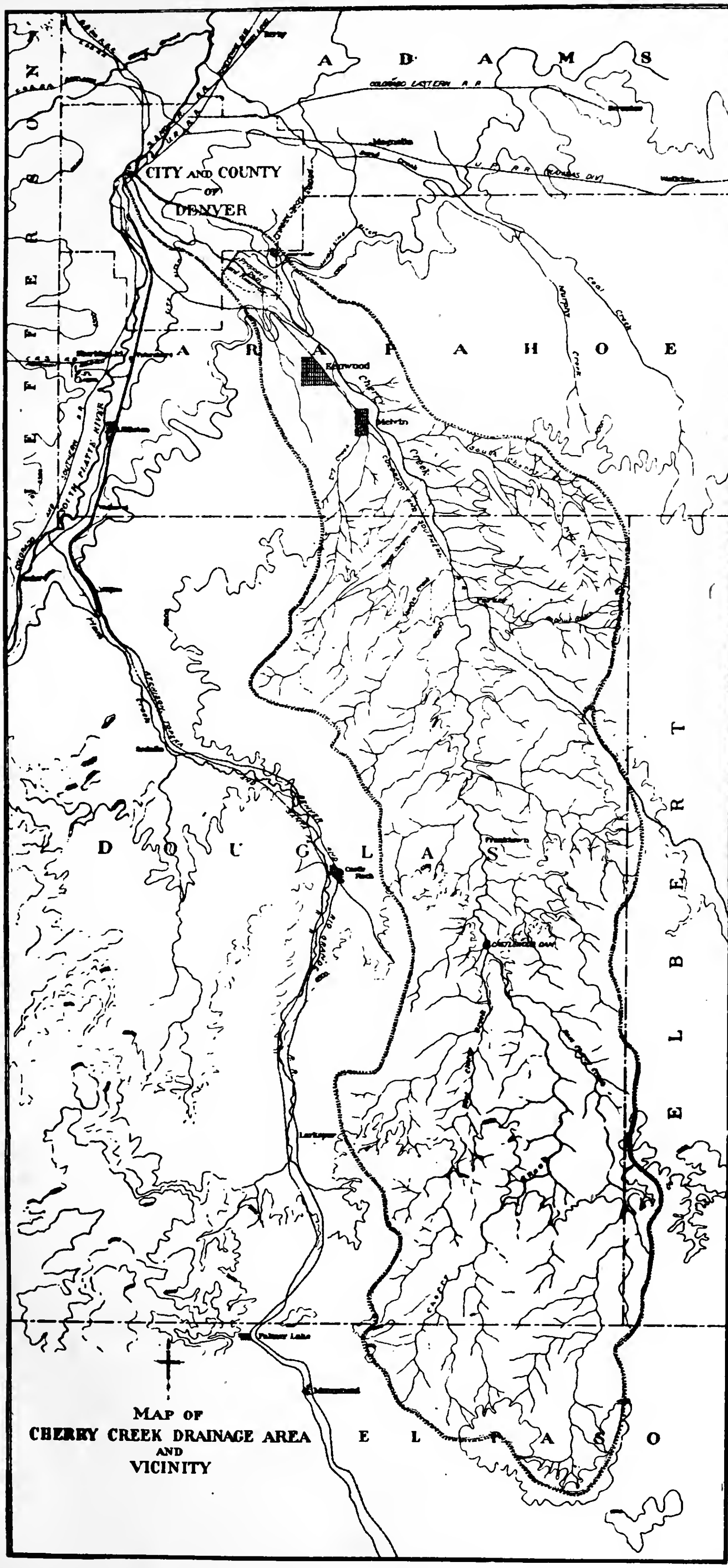
9. *Drift.*—A vast amount of drift of all kinds came down the stream, owing to the submerging of various portions of the valley above Denver, destruction of bridges, washing-away of buildings and trees, etc. This drift formed dams against practically every bridge in the city. This was true of the pile bridges and of the Blake Street bridge, where, as stated above, there were obstructions due to the construction of the Cherry Creek walls then under way. The dangers and resulting damages were augmented through the fact that the drift was collected into one mass. Under the conditions, it is remarkable that so much of the drift

found its way through to the South Platte River. Probably most of the greater part of such drift found its way through the streets of Denver rather than through the Cherry Creek channel.

CHERRY CREEK WATER-SHED

Floods that are discharged from any water-shed are obviously dependent upon the size and character of the drainage basin. The Cherry Creek water-shed extends from its junction with the South Platte River, previously described as being located approximately at the center of the city of Denver, to a point about fifty-five miles a little east of south of the city. It is generally of the type usually found in the semi-arid regions of the West, although, being located somewhat nearer the foothills, and its grades being somewhat greater than are found in most of the streams of similar character, it is probable that the floods are somewhat more frequent and violent than would be found to be the case generally for streams having water-sheds of practically equal extent. The total drainage area is 412 square miles. It is about fifty-five miles in length and at its widest point is approximately fifteen miles in width, this point being about twenty miles from Denver. The upper thirty-five miles of the basin has a fairly uniform width of about nine miles; the lower twenty miles varies from its maximum width of fifteen miles to nothing at the junction of the stream with the South Platte River. In general the course of the stream is nearly north, but for the last one-third of its course it flows practically northwest to its junction with the South Platte. Throughout its entire length the stream channel is practically in the center of the drainage basin. In altitudes the basin varies from approximately 5,175 feet at its mouth to about 7,700 feet at its source.

This entire region has been studied in detail by the United States Geological Survey, and the topography and geology of the Cherry Creek water-shed are given in detail in Monograph XXVII, United States Geological Survey, entitled "Geology of the Denver Basin in Colorado." To describe briefly the topography of the valley, it may be said to be usually rolling, although there are a few rocky and precipitous areas. There are no mountainous tracts, however, in the dainage area, and only a small portion of the water-shed is covered with timber. The greater part of the


A D A M S
COLORADO EASTERN R.R.
CITY AND COUNTY OF DENVER
A R A P A H O E
Englewood
Melvin
Parker
Franktown
Castle Rock
Larkspur
Palmer Lake
D O U G L A S
J E F F E R S O N
E L B E R T
E L P A S O
SOUTH PLATTE RIVER
Cherry Creek
Coal Creek
MAP OF
CHERRY CREEK DRAINAGE AREA
AND
VICINITY

district is settled and fenced, being used largely for stock-raising, dairying, and general farming. The valley proper is irrigated to some extent by the available normal water supply, which is generally small.

Geologically speaking, it may be said that practically the entire Cherry Creek water-shed is of the so-called Monument Creek formation, described by the geologists as being made up of "conglomerate, sandstone, and clay, rhyolitic tuff, two-thirds way up fifty feet thick." The Denver formation, which is found also in a considerable portion of the district, is described as follows: "upper half conglomerate, grit, sandstone, clay, all the debris of andesitic lava flows." The soil is generally a more or less sandy loam, varying from practically a clay to a sand, according to the locality. On the upper part of the water-shed the soil is of a much more loamy nature than in the lower portion. The greater part of the water-shed is covered with grass and brush of various kinds. About half-way down the course of the stream there is generally a moderate flow of water, amounting to several cubic feet per second. This water is generally diverted by irrigators or is lost in the sands of the channel, so that usually within the city limits there is practically no flow, with the exception of perhaps one or two cubic feet per second, excepting at times of flood discharge. It is apparent that the conditions in the drainage basin generally are conducive to a rather high run-off at the time of severe or protracted storms.

PRECIPITATION

The character of the precipitation has an important bearing upon flood discharge. Accordingly there are given, in the appendix, records of the monthly and annual precipitation, from the records kept by the United States Weather Bureau from 1872 to 1912, inclusive—a period of forty-one years. There are also given tables showing the greatest precipitation in twenty-four hours, for the same period of time, both by months and years, and a table showing the daily precipitation at Denver during the year 1912, for the months of January to October, inclusive. From these tables the following facts, in particular, are to be noted:

	Inches
Average annual precipitation in forty-one years	14.21
Maximum annual precipitation	22.96
Average monthly precipitation in forty-one years	1.18
Month of maximum average discharge, May	2.53
Individual month of maximum discharge, May, 1876	8.57
Maximum for twenty-four hours, May 21-22, 1876	6.53
Total for July 14, 1912	2.00

An examination of the records also shows that floods have occurred in practically all months excepting the colder months, in which the meteorological conditions are unfavorable to cloudbursts or rapid run-off.

Attention has already been called to the fact that the records at Denver do not necessarily, or even probably, show the actual precipitation conditions higher up in the Cherry Creek drainage basin, and still less throughout its entire area. The Denver precipitation may, however, be taken as fairly typical of the conditions that will prevail generally. It will be observed that the storm of July 14, 1912, was divided into at least two different sections—one center of precipitation being practically at Denver, and the other about twenty miles above Denver. Half-way between these two points the residents state that practically no precipitation occurred, it being said that "there was not enough rain to lay the dust;" consequently we have no means of telling what the precipitation was at its point of maximum occurrence. It may have been two inches, as at Denver, or it may have been much more than that. The maximum record for twenty-four hours for Denver is 6.53 inches, and amounts as great as this are known to have fallen in many sections of the semi-arid regions since records were first undertaken by the Weather Bureau.

Again, it is not possible to forecast as to how the precipitation will occur; for a storm may occur at a time when the ground is dry, and come in such a manner that a large portion of the precipitation will be absorbed or run off very gradually. On the other hand, it may occur at a time when the ground is saturated to its greatest possible extent, and if the flood comes with great intensity, the discharge might be nearly equal to the amount of precipitation. It is obvious here, also, that it is wise to prepare for the worst possible conditions that can reasonably be conceived. As is demonstrated beyond question by examination of the government records, it is not unusual for one storm of great intensity and magnitude to follow within a short time of another, thus finding conditions favorable to high run-off. At the time of the occurrence of the flood of July 14, 1912, the ground was generally dry and conditions were favorable for a high percentage of absorp-

tion. It is probable, therefore, that the run-off was not nearly so great as it would have been had the ground already been saturated at the time of the occurrence of the storm.

RUN-OFF

In the flood of July 14, 1912, the total volume of the run-off of Cherry Creek has been estimated at approximately 4,000 acre-feet. It is clear that the particular feature of the run-off in which we are especially interested is the amount of maximum discharge. This varies naturally with every flood. To illustrate this point, if we may assume that a total run-off of 4,000 acre-feet was to last for a single hour only, it would have to flow at an average rate of discharge for that hour of 48,000 cubic feet per second. The maximum discharge would be very much greater than that amount, as it would be physically impossible for a flood to discharge at an average rate throughout its entire duration. Assuming that the flood lasted for two hours, its average rate of discharge would be 24,000 cubic feet per second, of which the maximum might easily be, we may assume, 30,000. If the discharge were to cover a period of three hours, similarly the average flow would be 16,000 cubic feet per second, of which the maximum might be 20,000 or more. Or if the total run-off were to occur within a period of four hours, the average discharge would have to be 12,000 cubic feet per second, with a maximum somewhat greater, possibly 16,000 or more.

If it can be assumed that a general storm occurred over the entire Cherry Creek drainage area, varying in different portions of the area from two inches to six inches in twenty-four hours, with an average run-off of one inch from the entire surface, the total run-off would be over 21,000 acre-feet, or more than five times the amount that was estimated for the flood of July 14, 1912. Following the same line of illustration as that adopted above, and assuming a total run-off of 20,000 acre-feet, we see, if it were possible for the 20,000 acre-feet to flow through Denver in one hour, it would have to discharge at an average rate of 240,000 cubic feet per second. For two hours the average rate would be 120,000 cubic feet per second. For three hours the average rate would be 80,000 cubic feet per second; for four hours, 60,000; for six hours, 40,000; for twelve hours, 20,000, and for twenty-four

hours, 10,000. It is clear that the length of time consumed in discharging the total run-off is one of the prime factors in determining the maximum discharge.

An examination of the records available, showing the relation of run-off to rainfall, demonstrates that almost any proportion up to nearly 100 per cent is possible, the amount varying with the conditions. Some of these conditions may be mentioned, as follows:

1. The amount of precipitation.
2. Its intensity.
3. Condition of the surface on which the precipitation occurs.
4. Condition of the underlying strata.
5. Climatological conditions, including temperature, direction and velocity of the wind, etc.
6. Character and extent of vegetation.
7. Topography of the territory.
8. Amount of evaporation.
9. Nature of channels.

It is sufficiently obvious that no formula can be devised that can take into consideration all of the different conditions. Of course, if exact records were available for a great number of years — as, for example, several hundred years — such records might be used with a reasonable degree of confidence, but even then it would appear to be wise to allow a factor of safety of perhaps 25 per cent. Where no such records are available, recourse must be had to empirical formulæ, of which a number have been devised by different authorities, although always with the admission that they are unable to satisfy all conditions. Examination of these formulæ, and of tables and curves made from records, gives widely differing results, giving for the Cherry Creek area from 40,000 to 75,000 cubic feet per second.

POSSIBLE FLOOD DISCHARGE

Before arriving at any conclusions as to the proper remedies and safeguards to be adopted against Cherry Creek floods, it is obviously of the highest importance to ascertain as nearly as practicable what the maximum possible flood discharge may be at any time. It appears that within the fifty-four years of the city's history there has been at least one flood, the discharge of

which may be estimated at from 11,000 to 25,000 cubic feet per second, according to whether the point of measurement is made within the city or at points above the city. Possibly some of the other floods were as large, although the oldest residents of the Cherry Creek valley appear to be unanimously of the opinion that the maximum stage of the flood of July 14, 1912, was higher than for any preceding known flood. It is clearly possible, and even probable, however, as has already been stated, that a very much larger flood may come at any time. How much larger it is practically impossible to determine, but we may arrive at some conclusions as to what is possible by a study of floods on other streams in other more or less similar regions. As pointed out above by Mr. Freeman, "a maximum discharge of 11,000 second-feet at Denver would be equivalent to a rate of run-off of nearly twenty-five second-feet per square mile for the whole water-shed above Denver, and to fifty second-feet per square mile if only half the water-shed was affected by the storm." Mr. Freeman states that he is inclined to think that the latter premise is more nearly correct. Records of flood flow in the West, as given in the publications of the United States Geological Survey, show that fifty cubic feet per second per square mile is by no means a maximum discharge. The following records are taken from a table in the United States Geological Survey Water Supply and Irrigation Paper No. 147, page 188. Only a few of the records are given here:

RATE OF DISCHARGE OF STREAMS IN SOUTHWESTERN UNITED STATES IN SECOND-FEET PER SQUARE MILE

Stream and Place	Range Area in Sq. Miles	Date	Maximum Rate
Gallinas River, Las Vegas, N. M.	90	Sept. 30, '04	129.10
Mora River, La Cueva, N. M.	159	Sept. 29, '04	139.70
Canadian River, French N. M.	1,478	Oct., '04	105.56
Purgatory River, Trinidad, Colo.	742	Sept. 30, '04	61.20
Mora River, Weber, N. M.	422	Sept. 30, '04	65.70
Sweetwater River, Sweetwater Dam, Cal.	186	Jan., '94	97.50

We have also a creditable record of a flow of 60,000 cubic feet per second in Two Buttes Creek, southern Colorado, from an area of about 500 square miles, in October, 1908.

In *Engineering News,* Volumes LXII, No. 13, page 315, and *Transactions of the American Society of Civil Engineers,* Volume LXXII, pages 475-585, is given an account of floods at Monterrey, N. L. Mexico. For the purpose of comparison, a few facts are

given in connection with this drainage area of the Santa Catarina River above Monterrey:

Length of stream-bed, about 56 miles.
Water-shed area above city, 544 square miles.
Length of water-shed, 20 miles.
Maximum width, 28 miles.
Altitudes, 1,766 to 7,820 feet above sea-level.
Average rainfall for 21 years, 19.86 inches.

PRECIPITATION DURING STORM OF AUGUST 9 TO 11, 1909

Aug. 9—12 midnight to noon, Aug. 10	12 hrs.	3.50 in.
Aug. 10—12 noon to 8 a. m., Aug. 11	20 hrs.	7.11 in.
Aug. 11—8 a. m. to 6 p. m., Aug. 11	10 hrs.	2.77 in.
Total	42 hrs.	13.38 in.

PRECIPITATION DURING STORM OF AUGUST 25, 1909

Aug. 25—4 p. m. to 6 p. m.	2 hrs.	2.80 in.
Aug. 26—6 p. m., 25th, to 8 a. m., 26th	14 hrs.	.29 in.
Aug. 27—8 a. m., 26th, to 8 a. m., 27th	24 hrs.	.86 in.
Aug. 27—8 a. m. to 3 p. m.	7 hrs.	.96 in.
Aug. 27—3 p. m. to 6 p. m.	3 hrs.	.86 in.
Aug. 28—6 p. m., 27th, to 6 a. m., 28th	12 hrs.	6.85 in.
Aug. 28—6 a. m. to 9:30 a. m.	3½ hrs.	2.30 in.
Aug. 28—9:30 a. m. to 6 p. m.	8½ hrs.	2.12 in.
Aug. 29—6 p. m., 28th, to 7 a. m.	13 hrs.	3.04 in.
Aug. 29—7 a. m., 28th, to 6 p. m.	11 hrs.	1.53 in.
Total	98 hrs.	21.61 in.

Mean monthly rainfall for August, 21 years, 3.54 inches.
Mean monthly rainfall for September (wettest month in year), 4.276 inches.
Total recorded rainfall for August, 1909, 34.99 inches.
Maximum discharge, 235,000 cubic feet per second.
Cubic feet per second per square mile, 432.
Cubic feet per second per square mile in water-shed of the Estanzuela River, 3½ square miles, 825.

In the same articles are given two other examples of high run-off in foreign countries, as follows:

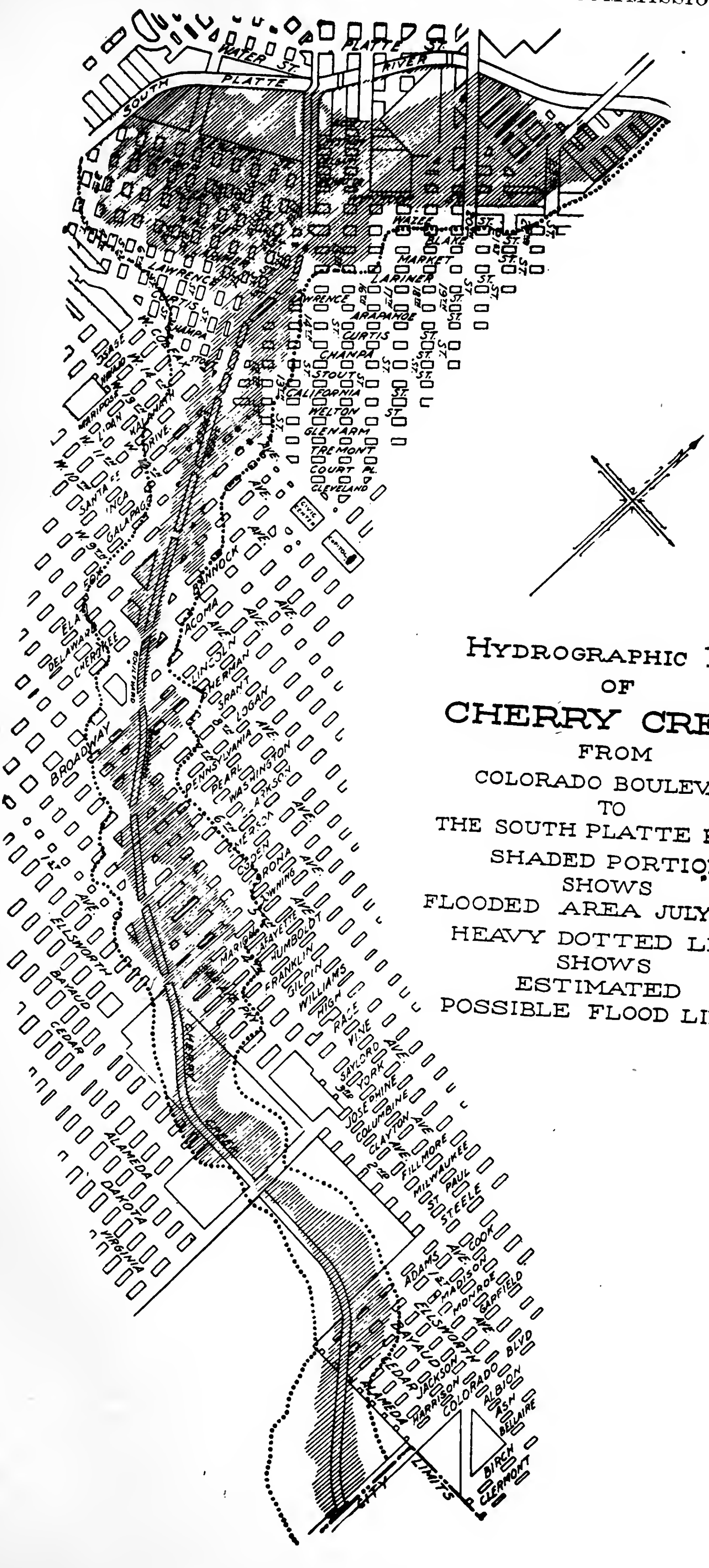
River	Drainage Area in Sq. Mi.	Maximum Reported Flow in Cu. Ft. per Sec.	Cu. Ft. per. Sec. per Sq. Mi.	Annual Amount of Rainfall in In.
Tanza, India	52.5	35,000	666.7	101
Krishna, India	345.	118,000	342.6	258

An examination of the foregoing data, and the study of the conditions relating to the different localities, would seem to indicate that the topography and general conditions for the Gallinas River at Las Vegas, N. M.; the Mora River at La Cueva, N. M.; the Canadian River at French, N. M.; the Purgatory River at Trinidad, Colo., and the Mora River at Weber, N. M., are fairly representative of the Cherry Creek, Colorado, conditions.

The topography in general is about the same in all of these localities; the altitude is approximately the same, while the conditions as to vegetation, forestation, etc., are not greatly dissimilar.

Professor E. C. Murphy, the author of Water Supply and Irrigation Paper No. 147, from which many of the foregoing data are taken, derives a certain formula and conclusions from the data

which he has compiled. He plots a curve showing the relation between the size of the drainage basin and the run-off per square mile, using as his data the flood discharges of streams of northeastern United States. By taking his formula and assuming it to be applicable to the Cherry Creek drainage area, there is obtained as a result the amount of approximately seventy cubic feet per second per square mile. Taking into consideration, however, the totally different character of the topographic and other conditions in the Cherry Creek drainage basin, as compared with those in northeastern United States, and taking into consideration also the flood data given above, it seems fair to conclude that a run-off of not less than twice the theoretical run-off for northeastern United States may be expected and should be provided for in the Cherry Creek drainage basin. Indeed, taking into consideration the records of the flood at Monterrey, Mexico, and other floods in foreign countries, and the possibility of the breaking of the Castlewood Dam, to be discussed later, which, while not considered probable, is possible, the Commission is led to the conclusion that 60,000 cubic feet per second may be reasonably assumed as a possible maximum flood. In other words, if it were assumed that a rainfall as great as has been known to occur at Denver, 6.53 inches in twenty-four hours, should occur over the entire drainage area, the storm advancing down-stream at approximately the same rate as the flow in the stream, with Castlewood Dam already filled with water and overflowing, the dam giving way at a critical stage of the flood, it is reasonable to suppose that from two to three times as much water would have to flow through Denver, at the maximum stage of the flood, as flowed at the point of maximum discharge of the stream in the flood of July 14, 1912. Or, assuming another possibility—viz., that a storm, or succession of storms, occurred over the whole Cherry Creek valley of intensity and duration of time similar to that prevailing in the case of the storm of July 14, 1912, but in such a way that the maximum discharge resulting from the storm or combination of storms arrived at Denver approximately all at once—then again it is reasonable to suppose that there might be a discharge of at least three times the amount of discharge occurring in the flood of July 14, 1912. Or, assuming still another contingency, which is shown to be possible by the records at Monterrey, Mexico, and other places, it might occur that one storm might follow another in such a way and at such a time as to multiply several times



HYDROGRAPHIC MAP
OF
CHERRY CREEK
FROM
COLORADO BOULEVARD
TO
THE SOUTH PLATTE RIVER
SHADED PORTION SHOWS FLOODED AREA JULY 14, 1912
HEAVY DOTTED LINE SHOWS ESTIMATED POSSIBLE FLOOD LIMIT

over what would have been the discharge of a single storm. In view of the considerations stated above, therefore, the Commission believes that it is justified in assuming the possibility of a discharge in Cherry Creek of 60,000 cubic feet per second for a short period of time.

There are shown on the accompanying plat the area actually covered by the flood of July 14, 1912, and also the area which it is estimated would be covered by the flood of 60,000 cubic feet per second. What such a flood, or even a flood of one-half that amount, would mean to Denver can hardly be imagined. It would certainly result in damages to the extent of many millions of dollars, and probably in the loss of many lives.

Objections are made by some to assuming as high a discharge as 60,000 cubic feet per second, on the theory that it is improbable that Cherry Creek will ever discharge so much water at one time. The members of the Commission believe, however, that it is possible, and that Denver should provide against the worst possible contingency rather than against the merely probable or average conditions. It is practically unquestioned that some of the water-shed areas in the State of Colorado, fairly comparable in their general character with the Cherry Creek water-shed, have actually furnished water at approximately the rate here assumed. This is demonstrated by the high-water marks on some of the streams in southeastern Colorado and by the flood of July 24, 1896, which occurred on Bear Creek, a tributary of the South Platte, a short distance above Denver. These facts, taken in connection with the possibility of a break in Castlewood Dam already referred to, which would probably result in even a larger discharge in Cherry Creek for a short space of time, if it were combined with general flood conditions, lead the Commission to conclude that it is wise to provide against an emergency as severe even as the one suggested.

A brief description of Castlewood Dam and Reservoir is given in the appendix.

FALL OF CHERRY CREEK CHANNEL

The fall of Cherry Creek is fairly uniform throughout its entire length, with the exception of two or three short sections. The following tables give the fall of the stream as determined by actual surveys for a distance of twelve miles from the city, and beyond that by estimates made from the United States Topographical Survey maps. The tables are as follows:

TABLE SHOWING ELEVATIONS OF SAND LINE OF CHERRY CREEK AND FALL OF STREAM BY SHORT REACHES THROUGH THE CITY FROM THE MOUTH OF CHERRY CREEK TO THE LOWER DAM SITE JUST EAST OF THE CITY LIMITS

Station	*Elevation	Distance between Stations	Fall in Ft. per 100 Ft.	Fall in Ft. per Mile
* 0-00	5,170			
30-00	5,184.4	3,000	.473	25
34-00	5,188	400	.90	47.52
48-00	5,192.8	1,400	.343	18.10
63-00	5,202.0	1,500	.613	35.90
75-00	5,207.0	1,200	.417	22.00
87-00	5,212.7	1,200	.475	25.10
106-00	5,223.4	1,900	.563	29.70
114-00	5,228.0	800	.575	30.40
116-08	5,232.68	208	2.25	118.80
122-00	5,236.20	592	.595	31.40
133-00	5,240.20	1,100	.364	19.20
145-00	5,246.20	1,200	.50	26.40
157-00	5,253.90	1,200	.642	33.90
169-00	5,261.50	1,200	.633	33.40
174-00	5,264.60	500	.70	36.90
186-00	5,271.00	1,200	.533	28.20
198-00	5,279.00	1,200	.667	35.20
210-00	5,286.80	1,200	.65	34.30
222-00	5,293.60	1,200	.567	29.90
234-00	5,301.5	1,200	.658	34.80
246-00	5,308.0	1,200	.541	28.60
258-00	5,316.0	1,200	.667	35.20
270-00	5,324.5	1,200	.708	37.40
282-00	5,330.5	1,200	.50	26.40
300-00	5,341.0	1,800	.583	30.80

*Remarks.—Mouth of creek.

TABLE SHOWING ELEVATION OF SAND LINE OF CHERRY CREEK BY LONG REACHES FROM THE LOWER DAM SITE TO UPPER DAM SITE

Station	Elevation	Distance between Stations	Fall in Ft. per 100 Ft.	Fall in Ft. per Mile
300-00	5,341	....	.583	....
310-50	5,345	1,050	.381	20.1
325-75 6 mi.	5,352	1,525	.459	24.2
346-50	5,364	2,075	.578	30.5
370-25 7 mi.	5,379	2,375	.633	33.4
381-10	5,383	1,085	.369	19.5
386-50	5,386	540	.556	29.3
391-20	5,388	470	.425	22.5
395-90	5,390	470	.425	22.5
422-30 8 mi.	5,407	2,640	.644	34.0
442-25	5,418	1,995	.551	29.1
458-50	5,426	1,625	.492	26.0
490-10 9 mi.	5,440	3,160	.451	23.8
496-60	5,447	650	1.077	56.9
503-50	5,447	690	.000	0.0
519-10	5,457	1,560	.641	33.8
527-70 10 mi.	5,462	860	.581	30.7
536-40	5,468	870	.69	36.4
546-70	5,474	1,030	.583	30.8
558-00	5,480	1,130	.531	28.0
567-90	5,485	990	.505	26.7
573-50 11 mi.	5,490	560	.893	47.2

Station	Elevation	Distance between Stations	Fall in Ft. per 100 Ft.	Fall in Ft. per Mile
583-50	5,494	1,000	.40	21.1
595-60	5,500	1,210	.496	26.2
600-60	5,502	500	.40	21.1
609-50	5,507	890	.562	29.7
616-50	5,510	700	.429	22.6
621-00	5,515	450	1.111	58.7
629-70	5,518	870	.345	18.2
635-60 12 mi.	5,521	590	.509	26.9
642-00	5,525	640	.644	34.0
649-00	5,528	700	.50	26.4
655-00 12.4 mi.	5,530	640	.33	16.4

TABLE SHOWING GRADIENTS OF CHERRY CREEK BY REACHES OF FIVE MILES EACH, FROM THE HEAD-WATERS TO THE MOUTH OF THE CREEK

Station	Elevation	Fall in Ft. per 100 Ft.	Fall in Ft. per Mile	Total Fall Five Miles	Total Fall From Station O
000	7,600	....	....	...	.....
000 to 5 mi.	7,275	1.23	65	325	325
5 to 10	7,075	.757	40	200	525
10 to 15	6,750	1.23	65	325	850
15 to 20	6,550	.757	40	200	1,050
20 to 22.75	6,250	2.066	109.1	300	1,350
22.75 to 25	6,150	.833	44	100	1,450
25 to 30	5,900	.947	50	250	1,700
30 to 35	5,800	.379	20	100	1,800
35 to 40	5,675	.473	25	125	1,925
40 to 45	5,530	.61	32.2	145	2,070
45 to 56.9	5,170	.549	29	360	2,430

An examination of these tables shows that the fall in general varies through a range of from about .33 foot per 100 feet to 2.25 feet per 100 feet for the portion of the creek surveyed, and, as shown by contour lines at five-mile intervals in the United States Topographical Survey maps, from .379 foot up to 2.066 feet per 100 feet. The average for 56.9 miles is 42.7 feet per mile. The average fall through the city appears to be practically .57 foot per 100 feet, or 30.1 feet to the mile. The following approximate estimates are of interest in this connection:

Estimates of Rates at Which Cherry Creek Floods of Assumed Volumes Would Travel from Castlewood Reservoir to Denver. Distance, 35 Miles, $n = .030$. The Estimates Are Based on a Comparison with the Flood of July 14, 1912.

	Rate	Time
One-half as large	4 miles	9 hrs.
Flood of July 14, 1912	7 miles	5 hrs.
One-third larger	7.75 miles	4½ hrs.
Two-thirds larger	8.50 miles	4 hrs.
Twice as large	9.30 miles	3¾ hrs.

PLANS PROPOSED FOR THE CONTROL OF CHERRY CREEK FLOODS AND THE PREVENTION OF RESULTANT DAMAGES TO THE RESIDENCE AND BUSINESS PORTIONS OF DENVER

A number of plans have been suggested in the press and directly to the Cherry Creek Flood Commission, which may be generally described as follows:

I. Retaining the present walls; extending them where necessary to the mouth of the creek and up to the eastern city limit; removing the weirs from the creek; raising bridges where practicable; paving the bed of the creek with concrete, and keeping the creek channel clear of all debris.

II. Raising the present walls along the creek to a sufficient height to carry the maximum flood.

III. Widening the present channel and raising the bridges sufficiently to permit the channel to carry the maximum flood waters without damage to property.

IV. The construction of a second channel by the side of the present one, completing both through the city; using this second channel as a driveway, excepting at the time of flood, when it would be utilized for the carriage of flood waters.

V. The construction of a diversion dam across the channel of Cherry Creek above the eastern city limit, and of a new channel eastward to Sand Creek.

VI. The construction of a diversion dam across Cherry Creek near the eastern city limit, and of a new channel westward to the Platte River near the south city limit, diverting Cherry Creek floods into Dry Creek.

VII. The construction of a diversion dam across Cherry Creek valley, and of a new channel from near the west end of the Country Club grounds westward to the South Platte River, or variations of this plan.

VIII. The construction of a diversion dam across the channel of Cherry Creek just below the crossing of the High Line Canal; enlargement of this ditch, and the diversion of the waters of Cherry Creek through the ditch for storage in reservoirs and use in irrigation.

IX. The construction of a diversion dam across the creek near Kenwood, and of a new channel northeasterly to Tollgate Creek, diverting the flood waters of Cherry Creek, to be stored in Tollgate Creek reservoir for irrigation purposes.

X. The construction of reservoirs along the bed of Cherry Creek and of its tributaries for the storage of the flood waters, to be used for irrigation purposes.

XI. The construction of a number of small regulating dams across the tributaries of Cherry Creek and on the upper portion of the main stream, for the regulation of floods.

XII. The construction of a concrete conduit in the present channel of Cherry Creek of sufficient capacity to carry approximately 10,000 cubic feet of water per second, and of regulating dams above the intake of this conduit for the regulation and control of the flood waters.

XIII. The construction of a dam at the eastern city limit sufficiently large to be used for the regulation of floods and for the control of the greater part of any maximum flood.

XIV. The construction of a reservoir of relatively small capacity, either within or a short distance above the city limits, which, together with a suitable spillway, could be used for the regulation of the run-off.

XV. The construction of a regulating reservoir, approximately at the eastern city limit, large enough to control waters of any flood considered possible.

Each of these plans has been studied by the Flood Commission, and the discussions of each plan, together with the conclusions of the Commission regarding the same, are given herewith:

I. COMPLETION OF CHANNEL AS FORMERLY PLANNED

This plan contemplates the retention of the present walls; extending them down the stream to its mouth, and up the stream to the city limits; removing the weirs from the channel as previously constructed; raising the bridges where practicable; paving the bed of the creek with concrete; and keeping the creek channel clear of sand, gravel, and debris generally.

The history of the walling of the creek up to its present stage is given elsewhere; attention being called to the fact that various ordinances have been passed fixing the width of the channel at amounts varying from 132 feet as a maximum to eighty feet, the width at which it is actually constructed. This plan contemplates, therefore, the extension of the walls above Downing Street to the city limits, giving the channel a width of eighty feet. Below Blake Street the width of the channel would be approximately ninety feet, as it is contemplated that the right of way will be 100 feet in width and about five feet will be necessary on each side for the construction of the wall. This plan also contemplates the removing of the weirs from the creek-bed. This has already been done in part, the crests of the weirs having been removed, although the footings of the weirs have been left in place

temporarily, for the purpose of preventing the stream from scouring to too great a depth.

Under this plan, also, certain of the bridges will have to be raised. The recommendations of the Commission regarding this feature are given in the report to the Board of Public Works, dated August 22, 1912. Paving the bed of the creek through its entire length with concrete has also been suggested in connection with this plan. A small amount of paving is now being attempted as an experiment just below the Broadway bridge, in accordance with the recommendation of the Commission. It has not as yet been demonstrated, however, that paving the bed of the creek will be a success.

The arguments urged in favor of paving are:

1. That it would provide a smooth-surfaced waterway, permitting of much greater velocity, and consequently greater discharge.

2. That the water passing over it would keep it scoured clean.

3. That it would save the city a large sum of money annually, which would otherwise be spent in cleaning the bed of the creek.

These arguments are believed by the members of the Commission not to have sufficient foundation to warrant the acceptance of this plan without its having been demonstrated over at least a section of the creek of reasonable length, as, for example, one thousand feet of the channel where the fall of the creek is least. The Commission feels that the pavement would generally be covered by sand in any case, as sand is constantly creeping along Cherry Creek from above and forming bars. This is true even when a flow of not more than two or three cubic feet per second is passing down the channel, and it is also certainly true of all moderate flows in the stream. At times of flood undoubtedly the sand would be carried through much more rapidly, and it is possible that the channel might be fairly clear during the time of the flood, but upon its subsidence the bars would begin forming again, and some of the anticipated benefits would thus be lost. Furthermore, there is obviously an element of danger in the existence of the paving, in case it should heave and be lifted by violent floods, as the Commission believes to be possible. It is known that in the flood of July 14, 1912, masses of concrete weighing many tons were carried for considerable distances down the stream. It seems reasonable, therefore, to assume that, if such a

flood, traveling at the rate of approximately thirty feet per second, or twenty miles per hour, should find an entrance under the pavement at any point, it might rip it loose in long sections and pile it up as cordwood might be piled. Furthermore, there would be a disadvantage to the city in removing to some extent its best supply of sand. Denver is largely built with the aid of Cherry Creek sand, and the sand removed from Cherry Creek by dredging and otherwise during the history of the city has been worth hundreds of thousands of dollars. In this connection, however, it should be noted that there is a tendency to remove the sand to too great a depth—a practice which has heretofore been protested against by the members of the Flood Commission.

To obviate this danger, the Commission believes that a grade line should be physically established; that curtain or cut-off walls be constructed across the stream at suitable intervals, for the purpose of maintaining the grade as established, and that no one be permitted, under heavy penalty, to take sand from the creek-bed below the established grade line. The Commission believes that these curtain walls would practically serve every useful purpose that could be served by the proposed pavement, without the attendant danger, and at one-tenth the cost. This plan obviously entails the necessity of keeping the channel reasonably clean, as does, or should, practically every other plan proposed. This the Flood Commission believes to be absolutely essential; and it may be stated here that, whatever course is adopted, the Commission believes that the channel should be kept reasonably clear, and that dumping into the channel, or causing obstructions in any way, should be heavily penalized. Commenting upon this plan in general, it may be stated here that the Flood Commission believes it to be of the utmost importance that the walls be constructed as now planned by the Engineering Department, from Blake Street to the mouth of the creek; that the channel be excavated, wherever necessary, throughout its course through the city to a properly established grade, which grade has heretofore been determined by the Commission and recommended to the Board of Public Works; that curtain walls be constructed at suitable intervals, depending upon the fall of the stream; that the recommendations as to bridges made in the report of the Commission dated August 22, 1912, be followed; that, as rapidly as practicable, walls be extended from Downing Street up to the city limits; and that all obstructions, including the foundations of the weirs previously described, be removed to the official grade.

It is obvious that this channel would have a carrying capacity of approximately 10,000 cubic feet per second throughout its entire length through the city, provided that the water in South Platte River was not so high as to decrease the hydraulic gradient to any material extent. This channel would clearly not be sufficient in size to carry the maximum flood which the Commission has concluded is possible. It would, however, take care of any flood known to have passed through the city up to the present time, and the Commission believes, as will be shown later, that the floods can be so regulated as to render it practically absolutely certain that the channel would be of sufficient size to carry off any water that could possibly come down.

II. RAISING THE PRESENT WALLS

To carry a flood of 60,000 cubic feet per second with a stream of the present width would require the raising of the walls, and also of the bridges, to an additional height of approximately twelve feet. This would entail also the strengthening or replacing of the present walls; the raising of the bridges and adjacent streets, resulting in great damage to property, and would create a veritable eyesore throughout the entire city. Even for a flood of 30,000 second-feet the disadvantages would obviously be so great that the plan has not been considered in detail by the Commission, as it believes this to be probably the least advantageous, and attended with the greatest disadvantages, of any of the plans proposed.

III. INCREASING THE WIDTH OF THE PRESENT CHANNEL

This plan has been presented in a report made by a committee of three—Dr. F. L. Bartlett, D. W. Brunton, M.E., and L. G. Carpenter, C.E.—appointed by the Chamber of Commerce "to ascertain the most desirable method of preventing damage to the residence and business portions of Denver by Cherry Creek floods." This report is given in full in the appendix, and reference may be had thereto. Briefly considered, the following points are to be noted:

This committee suggests seven different plans, as follows:

1. A storage dam on Cherry Creek at some convenient point above the city, large enough to hold all of the waters liable to accumulate during any single downpour.

2. A storage dam similarly located, sufficiently large to hold from one-half to two-thirds of the maximum flood waters, the

remaining portions to be permitted to pass on and reach the South Platte through the present channel of Cherry Creek.

3. A number of small dams on the tributaries of Cherry Creek and a small dam on the main stream just above the highest tributary dammed.

4. A diversion dam across the channel of Cherry Creek about seven and one-half miles above its confluence with the Platte, and a channel sufficiently large to carry the flood water of Cherry Creek eastward over into Sand Creek channel, from which they would eventually find their way to the Platte without doing serious damage.

5. A diversion dam across Cherry Creek near the proposed location of No. 4, and a canal running to the westward and discharging the flood waters of Cherry Creek into the Platte River near its entrance into the city.

6. Changing the course of Cherry Creek from the west end of the Country Club grounds to the Platte River by cutting a straight channel due west to the river.

7. Enlarging the present Cherry Creek waterway sufficiently to permit it to carry off the floods without damage to residential or city property.

These plans are discussed briefly by the committee, but, as they will be discussed in somewhat greater detail herein, and as the report of the committee is given in full in the appendix, as stated, discussion is not given here, excepting to give the conclusions of the committee, which are as follows:

"Until further information and data are obtainable, your committee does not feel justified in selecting any particular plan, but it is reasonably certain that comparatively inexpensive preliminary surveys and estimates will eliminate four or five of the proposed schemes, so that more costly and final surveys and estimates will not be necessary on more than two or three of them. To summarize our conclusions:

"(1) Floods must be expected at irregular intervals, and whenever a combination of favorable conditions occurs they may be larger than any we have yet seen.

"(2) In case these floods are not lessened by the construction of reservoirs, it is evident that a waterway must be maintained of sufficient size and grade to care for them within the banks of the channel. Other things being equal, the smoother the sides and

bottom, the straighter the channel and the greater the fall, the more water is carried by a conduit of a given size.

"(3) Increased waterway may be obtained either by deepening or broadening the channel, or by removing the obstructions and raising the bridges, and prohibiting its use as a dumping-ground.

"(4) If it be finally determined that the diversion of Cherry Creek is the most advantageous, it is proper to call attention to the fact that the present channel could not be entirely dispensed with, because of the great volume of water entering and originating below the point of diversion.

"(5) To form final judgment of the best and most effective means of preventing future damage requires information and data which can be had only by actual surveys and estimates based thereon. The importance of the interests involved and of the possibilities of damage justifies a thorough study of conditions, and we recommend that, before action is begun and a definite plan adopted, all obtainable information and data be submitted to and passed on by a competent board of engineers.

"Respectfully submitted,

"DR. F. L. BARTLETT.
"D. W. BRUNTON, M.E.
"L. G. CARPENTER, C.E."

This committee, as will be noted, did not make any definite recommendation, but suggested that surveys and estimates based thereon should be made, and stated that the importance of the interests involved justified a thorough study of conditions. The only recommendation made was along this line, that all obtainable information and data be submitted to and passed on by a competent board of engineers. Verbally, however, the members of this Commission have discussed somewhat more in detail the plan of widening the present channel to a width of 110 feet and concreting the bed of the stream, the concrete to take the form of an inverted arch, in practically the form of an arc of a circle; the center grade of the stream being three feet lower than the point where the paving joins the walls. This plan would entail the removal of one of the walls and the widening of the channel thirty feet, if the channel were to be made 110 feet. It would also necessitate the reconstruction of all of the bridges along the stream-bed. Such a channel, if the paving could be relied upon, would provide against damages from any ordinary flood and from

floods even much larger than the one of July 14, 1912. Unless made of considerably greater width than 110 feet, however, it would not protect the lower part of the city in case of such a flood as is deemed possible, as shown by the following estimates of discharge for streams of different width. This table is based on the Kutter formula, assuming the fall of the stream twenty-five feet per mile and using in the Kutter formula $n = .014$ for concrete surfaces and $n = .030$ for an unpaved surface. The results are recognized as roughly approximate only, but they will give some suggestion as to the necessary widths for discharging floods of different amounts.

TABLE GIVING APPROXIMATE WIDTHS FOR VARYING CONDITIONS

Character of Section	Flood Discharge in Sec.-Ft.	Slope in Ft. per Mile.	Depth	Coefficient n	Velocity in Ft. per Sec.	Necessary Width
Paved	60,000	25	10.5	.014	30.42	188
Paved	30,000	25	10.5	.014	28.92	99
Unpaved	60,000	25	12.0	.030	17.00	294
Unpaved	30,000	25	10.5	.030	15.35	187

From the foregoing table it may be seen that there would be required a channel, if paved, of an average depth of 10.5 feet and with a width of 188 feet, to take care of 60,000 cubic feet per second, or a width of 99 feet to take care of a flood of 30,000 cubic feet per second. In both of these cases the average velocity would be in the neighborhood of 30 feet per second.

In an unpaved channel for a flood of 60,000 cubic feet per second there would be required a depth of 12 feet and a width of 293.8 feet, with a velocity of 17 feet per second; and for a flood of 30,000 cubic feet per second, a channel with an average depth of 10.5 feet and a width of 187 feet, with a velocity of 15.35 feet per second.

As previously stated, the Commission thinks, in the light of present information, that it would not be safe to depend upon paving until its success shall have been fully demonstrated. It is to be remembered also that a fall of twenty-five feet per mile is approximate only. The actual fall of Cherry Creek is shown in tables previously given. It will be observed that the fall is sometimes much more than twenty-five feet per mile and sometimes much less. It is unfortunate that official grades as nearly uniform as possible throughout the city were not established before the construction of any of the walls. This, however, was not done, and the minimum grades, therefore, become of prime importance. As is well known, however, the actual discharge of the stream

depends upon the hydraulic grade, or the fall of the surface of the stream, rather than upon the grade of the bed of the stream.

Attention is called to the estimated velocities, and particularly those for paved sections. A velocity of thirty feet per second is a terrific velocity for a stream of this character. Logs running at such a rate would have a tremendously destructive effect, if the water should rise to the height of the bottoms of any of the bridges.

The Commission believes that widening the channel is not warranted at this stage of the evolution of the Cherry Creek channel, as there appear to be better plans for controlling the stream flow. Comparison of the different methods will be made in summarizing the situation.

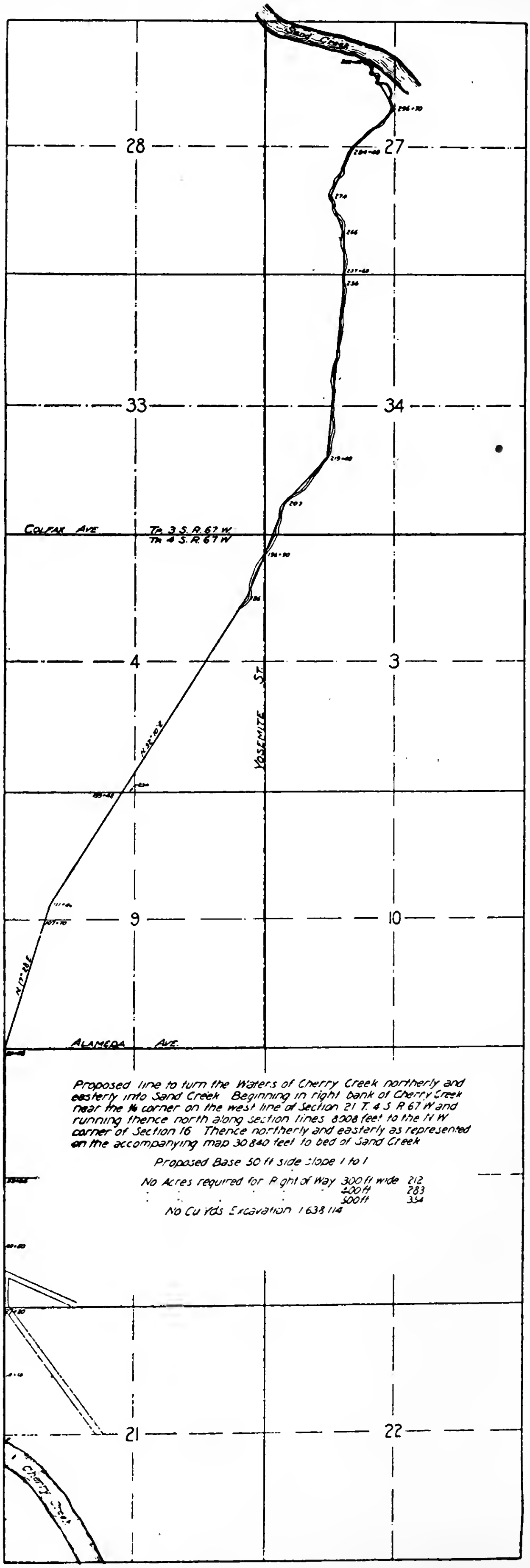
The following estimate of cost of widening the channel to 110 feet from the South Platte River to Downing Street is given herewith.

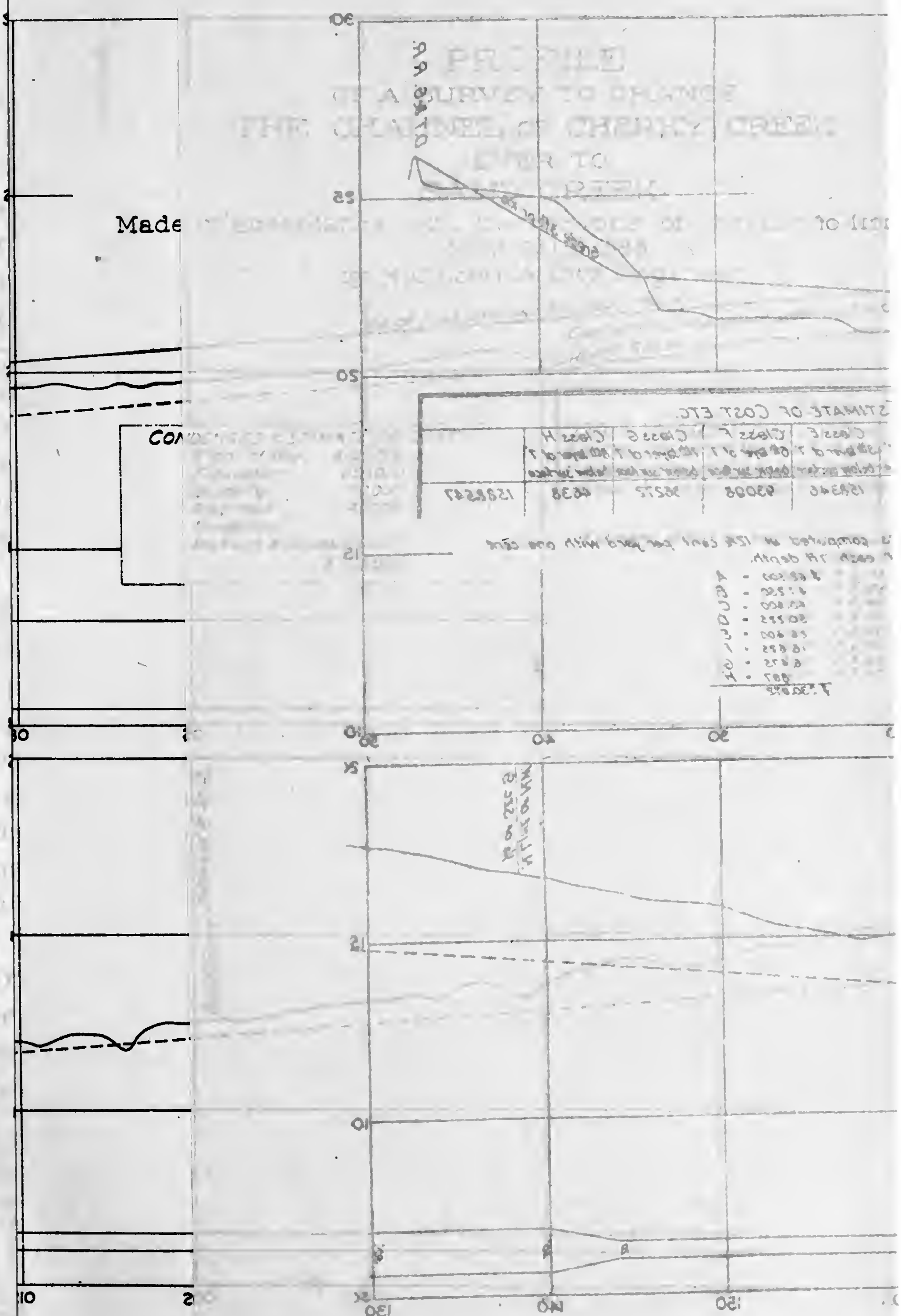
APPROXIMATE ESTIMATE OF COST OF WIDENING CHERRY CREEK CHANNEL FROM EIGHTY TO 110 FEET FROM BLAKE STREET TO DOWNING STREET, AND FROM 100 TO 110 FEET FROM BLAKE STREET TO THE SOUTH PLATTE RIVER

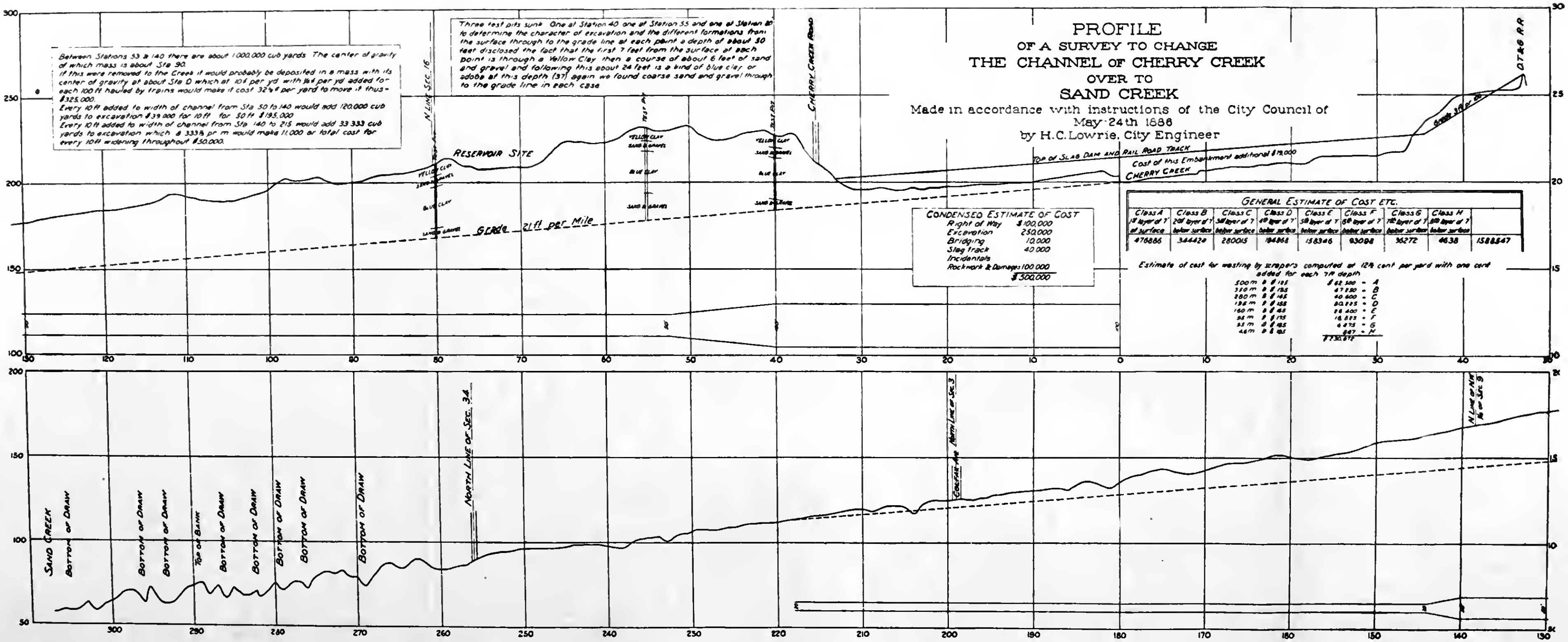
14,100 linear feet of concrete wall to be removed, at $2.00	$ 28,200.00
141,000 cubic yards of excavation, at $0.40	56,400.00
14,100 linear feet of new reinforced concrete wall, at $9.00	126,900.00
11,500 linear feet of concrete curb and gutter to be removed, at $0.20.	2,230.00
Extending sewers, and new inlets and connections	7,000.00
Sixteen new bridges to be constructed, at $40,000 each	640,000.00
Right of way for new driveway	169,860.00
	$1,030,590.00
193,600 square yards of concrete pavement for bed of creek, at $1.25.	242,000.00
Total	$1,272,590.00

IV. A SECONDARY CHANNEL

This plan is similar to Plan No. III, but with the exception that the widened channel would be divided into two parts by a division wall, one channel being used regularly for the flow of Cherry Creek and the other channel being provided with gates, so that it would be possible to turn Cherry Creek waters into this portion of the channel, either automatically or otherwise. It is suggested that the second half of the channel might be used ordinarily as a driveway, speedway, etc. What has been said in regard to Plan No. III is generally applicable to this plan also, and the Commission is not in favor of this plan, for reasons already stated. This plan, however, might have the advantage that at least one-half of the channel might be made useful for traffic along Cherry Creek by constructing runways from the general street levels down into the channel. This driveway would then take the place of the driveway on one or the other of the two


Sand Creek
28
27
33
34
Colfax Ave
Tp. 3 S. R. 67 W.
Tp. 4 S. R. 67 W.
4
3
Yosemite St.
9
10
Alameda Ave.
Proposed line to turn the Waters of Cherry Creek northerly and easterly into Sand Creek Beginning in right bank of Cherry Creek near the ¼ corner on the west line of Section 21 T. 4 S R 67 W and running thence north along section lines 8008 feet to the N W corner of Section 16 Thence northerly and easterly as represented on the accompanying map 30 840 feet to bed of Sand Creek
Proposed Base 50 ft side slope 1 to 1
No Acres required for Right of Way 300 ft wide 212
400 ft 283
500 ft 354
No Cu Yds Excavation 1 638 114
21
22
Cherry Creek


Made
30
210


PROFILE
OF A SURVEY TO CHANGE
THE CHANNEL OF CHERRY CREEK
OVER TO
SAND CREEK
Made in accordance with instructions of the City Council of May 24th 1886
by H. C. Lowrie, City Engineer
Between Stations 33 & 140 there are about 1,000,000 cub yards. The center of gravity of which mass is about Sta 90.
If this were removed to the Creek it would probably be deposited in a mass with its center of gravity at about Sta 0 which at 10¢ per yd with ¼¢ per yd added for each 100 ft hauled by trains would make it cost 32½¢ per yard to move it thus-$325,000.
Every 10 ft added to width of channel from Sta 50 to 140 would add 120,000 cub yards to excavation $39,000 for 10 ft for 50 ft $195,000
Every 10 ft added to width of channel from Sta 140 to 215 would add 33,333 cub yards to excavation which @ 33⅓ pr m would make 11,000 or total cost for every 10 ft widening throughout $50,000.
Three test pits sunk. One at Station 40 one at Station 55 and one at Station 80 to determine the character of excavation and the different formations from the surface through to the grade line at each point a depth of about 30 feet disclosed the fact that the first 7 feet from the surface at each point is through a Yellow Clay then a course of about 6 feet of sand and gravel and following this about 24 feet is a kind of blue clay or adobe at this depth (37) again we found coarse sand and gravel through to the grade line in each case
N LINE SEC. 16
RESERVOIR SITE
TEST PIT
YELLOW CLAY
SAND & GRAVEL
BLUE CLAY
CHERRY CREEK ROAD
Grade 21 ft per Mile
TOP OF SLAG DAM AND RAIL ROAD TRACK
Cost of this Embankment additional $19,000
CHERRY CREEK
D.T. & G. R.R.
CONDENSED ESTIMATE OF COST
Right of Way $100,000
Excavation 250,000
Bridging 10,000
Slag track 40,000
Incidentals
Rockwork & Damages 100,000
$500,000
GENERAL ESTIMATE OF COST ETC.
Class A 1st layer of 7' of surface 476886
Class B 2nd layer of 7' below surface 344424
Class C 3rd layer of 7' below surface 280015
Class D 4th layer of 7' below surface 194868
Class E 5th layer of 7' below surface 158346
Class F 6th layer of 7' below surface 93098
Class G 7th layer of 7' below surface 36272
Class H 8th layer of 7' below surface 4638
1588547
Estimate of cost for wasting by scrapers computed at 12½ cent per yard with one cent added for each 7 ft depth
SAND CREEK
BOTTOM OF DRAW
TOP OF BANK
NORTH LINE OF SEC. 34
NORTH LINE OF SEC. 3
COLFAX AVE
N LINE OF NW ¼ OF SEC. 9

sides of the channel—probably the one on the west side. Its disadvantages would be similar to those mentioned in regard to Plan No. III. No estimate of cost has been made for this plan.

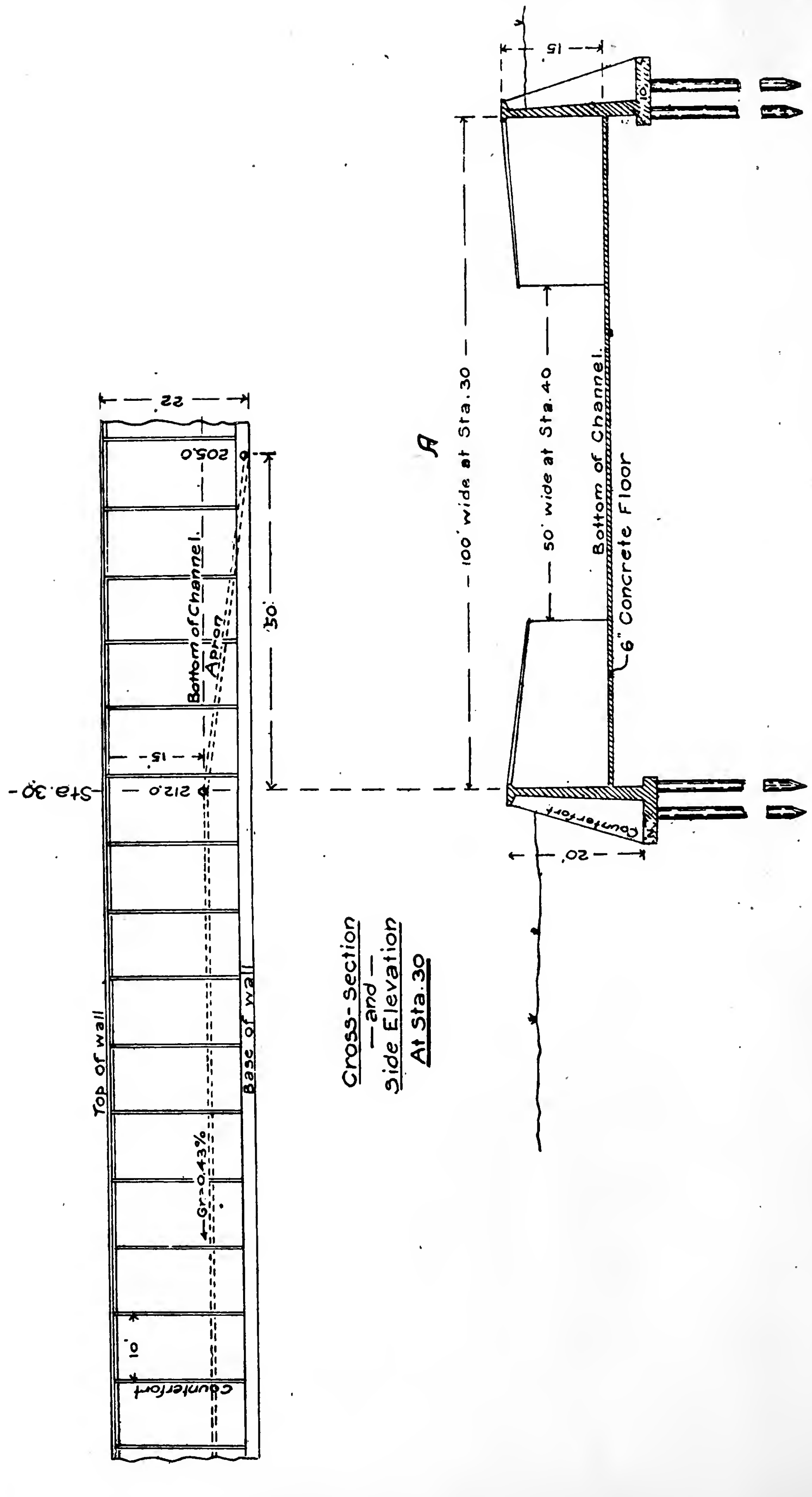
V. SAND CREEK DIVERSION

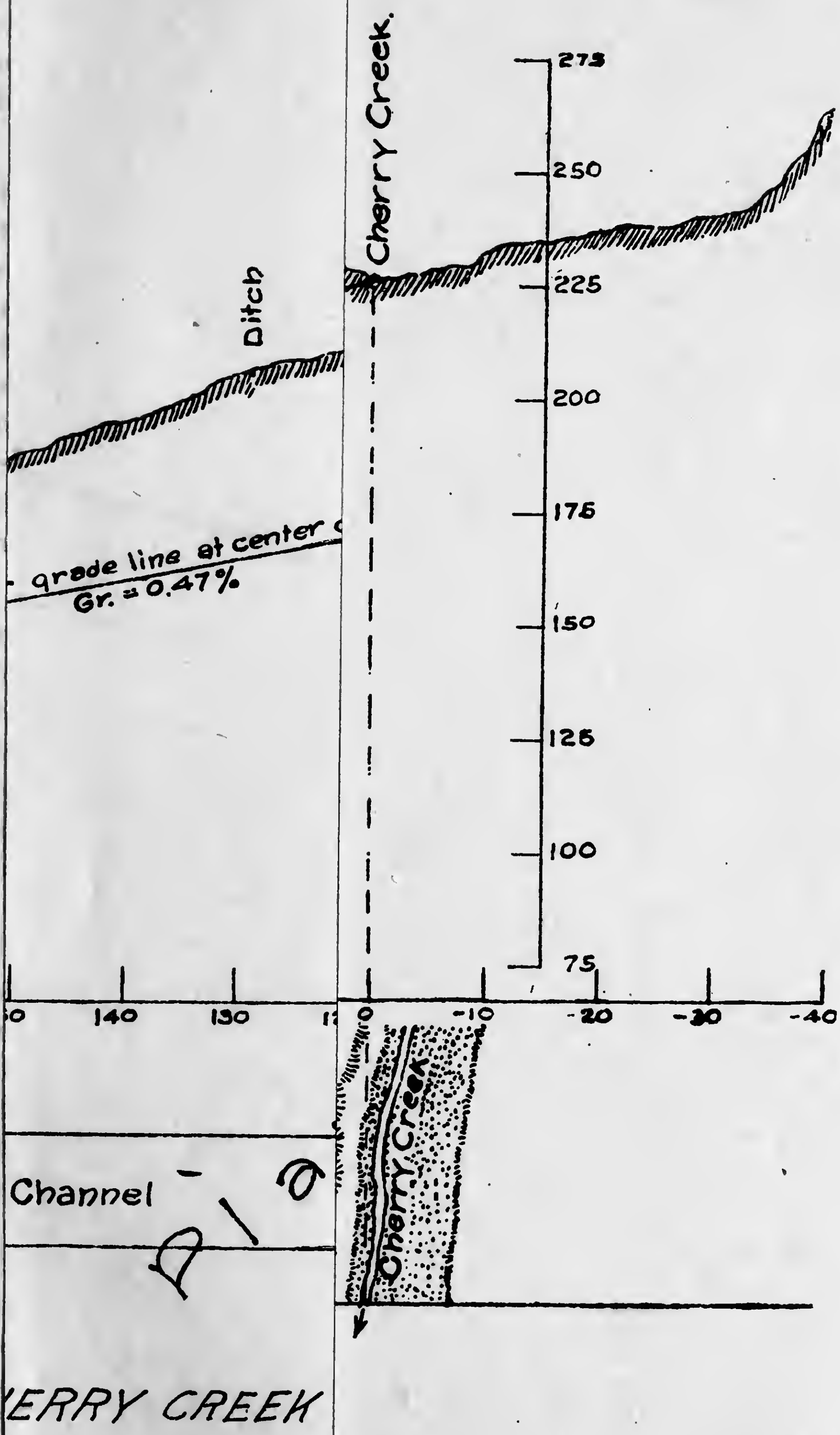
The flood of July 26, 1885, resulted in the preliminary consideration of the possibility of diverting Cherry Creek to Sand Creek. With this end in view, a survey was made by Mr. H. C. Lowrie, City Engineer, in the year 1886, and the cost of such diversion was estimated at $500,000. This estimate covered the construction of a new channel and of a new right of way, as recommended by Mr. Lowrie. His plans contemplated the construction of a slag diverting dam, a mile in length, across the Cherry Creek valley, water being turned into a canal 100 feet wide on the bottom, running directly north for the first mile, then running north and northeasterly 1.73 miles with channel fifty feet on the bottom, thence northerly 1.4 miles with a width of twenty feet on the bottom; the entire channel to this point having a fall of twenty-one feet to the mile. From this last-described point the water was to flow northerly 1.7 miles to Sand Creek, being then turned into a small ravine to make its own channel; in fact, it was expected that it would erode its own channel to a great extent after passing through the first mile of the canal. Hon. Joseph E. Bates, then Mayor, estimated that it would cost more than one million dollars for the construction, right of way, damages, and damage suits that would accrue in case the contemplated change was made. No results of any consequence followed these investigations. The differences of opinion as to the cost and as to the benefits that would be derived from such diversion were apparently so great that no concerted action seemed possible.

One of the first official acts of the Flood Commission was to go over the line, and later a resurvey of the proposition was made. As result of this resurvey, the plans of which are given herewith, the following estimate was made:

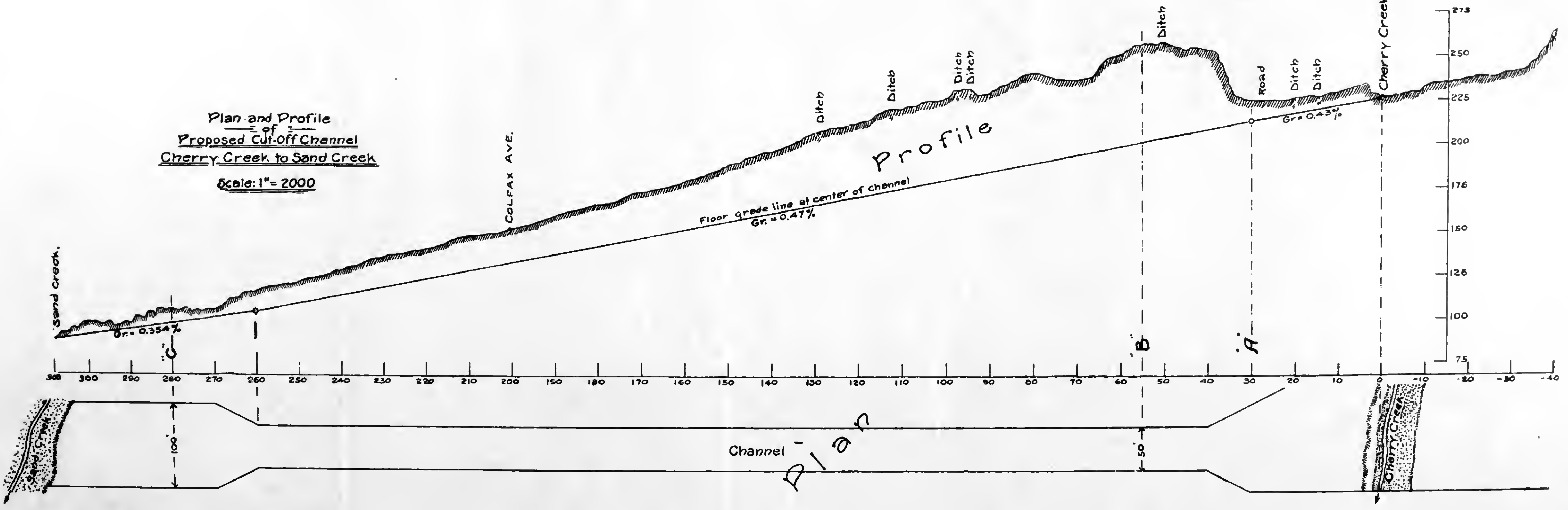
APPROXIMATE ESTIMATE OF THE COST OF TURNING CHERRY CREEK BY CONSTRUCTING A NEW CHANNEL TO CONDUCT THE WATERS INTO SAND CREEK

2,263,249 cubic yards excavation, at $0.15	$ 339,487.35
7,000 linear feet concrete wall for diverting dam, at $30.00	310,000.00
45,400 linear feet concrete wall for channel, at $15.00	681,000.00
10,200 linear feet concrete wall for channel, at $9.00	91,800.00
150 acres for right of way, at $500.00	75,000.00
141,000 square yards of concrete paving, at $1.00	141,000.00
Bridges	100,000.00
	$1,638,287.35
Engineering and incidentals	49,148.62
Total	$1,687,435.97


Cross-Section
—and—
Side Elevation
At Sta. 30
A
100' wide at Sta. 30
50' wide at Sta. 40
Bottom of Channel.
6" Concrete Floor
Counterfort
15
20'
22
205.0
212.0
Sta. 30
30'
15'
Bottom of Channel.
Apron
Top of wall
Base of wall
Gr.=0.43%
10'
Counterfort



Cherry Creek.
Ditch
grade line at center
Gr. = 0.47%
275
250
225
200
175
150
125
100
75
140
130
0
-10
-20
-30
-40
Channel
Cherry Creek
ERRY CREEK



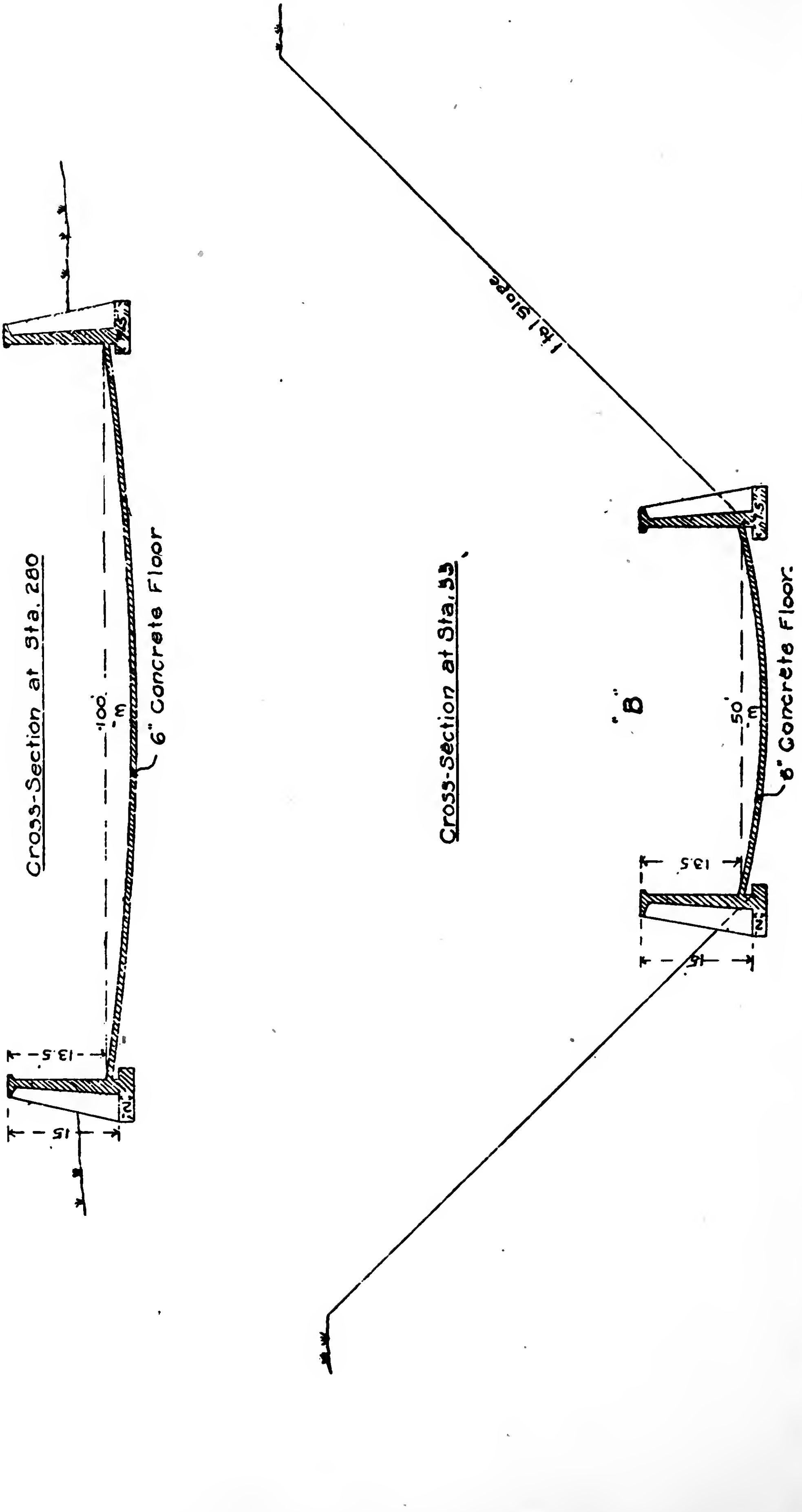
ADOPTED BY CHERRY CREEK FLOOD COMMISSION

The foregoing estimate does not take into consideration the possible damages resulting to owners of property lying to the eastward of the proposed diversion canal and along Sand Creek. Doubtless suits for damages would be numerous, and it would be impossible to tell what this plan might eventually cost the city. The following objections to the plan should be noted:

1. This plan would require, first, a diversion dam across the entire channel, which would have to be supplied with gates, as it would be necessary to turn at least small amounts of water down the stream for the benefit of those entitled to its use. Unless this were made a very expensive dam, there would be danger of its being overtopped or broken at critical times, and the result would be more serious to the valley below than would be the case if the flow came down unimpeded. The result of such a break would be that a considerable amount of impounded water would be added to the natural storm discharge, and greater damages would ensue than would be the case without such a dam.

2. The estimate given above does not contemplate a canal large enough to take the maximum flood assumed possible by the Commission. Probably it would not carry with safety more than one-half the water which might possibly come down the creek upon the occurrence of such a flood, in which case the diversion dam would be destroyed and the entire flood would overflow the channel, causing probably vastly more damage than would have been the case had matters been left as they were.

3. The city would be liable for all damages caused by the change, and it is even doubtful if the change would be permitted, as is illustrated by the case of the flood of July 20, 1875. Undoubtedly all owners of either residence or farm property lying just to the east of the canal would deem themselves injured and would claim damages from the city. It would also require numerous bridges across the canal, greatly increasing the cost of the undertaking. Certainly, moreover, the city would be liable for damages caused to railroad bridges, highway bridges, and farm, residence, and business property along Sand Creek, should it be damaged at any time by floods diverted from Cherry Creek to Sand Creek. It seems to be the general trend of judicial decisions that in cases of such floods as that of July 14, 1912, the city is not liable for damages, provided the water is left in the natural channel, but it is liable for all damages resulting from diversion to artificial channels.


C
Cross-Section at Sta. 280
100'
6" Concrete Floor
13.5
15
"B"
Cross-Section at Sta. 33
50'
6" Concrete Floor.
13.5
15

4. The diversion canal would have to be so far up the stream that a very considerable proportion of the drainage area of Cherry Creek would still have to be taken care of by the present channel. In the opinion of the Commission, it would hardly be safe to reduce the size of the present channel to any considerable extent, even if the plan of diverting the water from Cherry Creek to Sand Creek, as proposed, were to be followed.

For the foregoing reasons, and the impracticability of determining what the total cost would be to the city, the Flood Commission does not approve this plan.

VI. DRY CREEK DIVERSION

This plan is similar to Plan No. V. It has been studied in some detail by the Cherry Creek Flood Commission, but is decided against for the same reasons that influenced the Commission in connection with the proposed Sand Creek diversion canal. Its cost would be not far from the same amount, and it would have the additional disadvantage that the flood water would be turned into the river above the city, which fact would endanger the lowlands along the river, particularly at times when floods occur simultaneously in both Cherry Creek and South Platte drainage above Cherry Creek.

VII. DIVERSION AT DOWNING STREET, ETC.

This plan has been suggested in a number of different forms, with slight variations. The Flood Commission does not favor any of these plans, for the reasons already stated, and for the further reason that, starting at the point proposed, it would be necessary to carry the diversion canals through well-populated parts of the city, where great damage would be done by the construction of such canal as would be required, as well as by the possibilities of overflowing the banks at times of maximum floods.

VIII. DIVERSION INTO HIGH LINE CANAL

This plan contemplates the construction of a diversion dam similar to those already discussed, at a point just below the crossing of Cherry Creek by the irrigation canal of the Northern Colorado Irrigation Company, or, as it is more generally known, the High Line Canal, this point being located about four miles up Cherry Creek from where it crosses the eastern city limit. It would also require the enlargement of this canal from its present capacity, which is understood to be about 600 cubic feet per second,

to a capacity sufficiently large to take care of the largest floods in Cherry Creek, or at least a considerable portion of such floods. Reservoirs for the storage of such flood water as might be diverted would also be necessary. So far as is known to the Flood Commission, this plan has never been worked out in detail; consequently it is impossible to give an estimate of cost. Similar objections apply, however, to such proposed diversion as apply to the plans already discussed. There are also other objections to this plan in addition to those mentioned in the other cases. The High Line Canal, being constructed upon a light grade, approximately two and one-half feet to the mile, instead of twenty-three feet to the mile, as would be possible in case of the Sand Creek diversion, would have to be made very much larger than would be necessary for the proposed canal to Sand Creek, if it be assumed that the floods were to be carried on the normal grade of the High Line Canal. In this case, moreover, it is certain that floods coming down the Cherry Creek valley and heavily charged with earth, sand, and gravel, as well as all kinds of drift, would speedily fill the channel of any ditch constructed on a light grade. Moreover, the great majority of floods in Cherry Creek occur at times when the water is needed by prior appropriators, for irrigation purposes along the South Platte River as far down as the Nebraska line, and such floods could not legally be impounded for irrigation purposes by any new appropriators. Floods coming at such times and in such quantities as could legally be used are so extremely rare that the waters would be of little service for irrigation.

IX. TOLLGATE CREEK DIVERSION

This plan contemplates the construction of a diversion dam, as in the last case, excepting that it would be some two or three miles farther up the stream and would have the advantage of permitting of a canal with a much greater fall than would be possible in the case of Plan No. VIII. However, it has practically all of the other objections mentioned in the preceding cases, and the Flood Commission does not favor it, believing, as it does, that all of these proposed diversion propositions are inadequate and impracticable, as well as being very costly. So far as the irrigation feature is concerned, the Flood Commission believes it is not practicable for the city to enter into the practice of irrigation on any large scale through the storage of flood waters of Cherry Creek.

X. CONSTRUCTION OF A NUMBER OF RESERVOIRS

This plan contemplates the construction of a number of reservoirs of greater or less size along Cherry Creek and its tributaries for the purpose of holding back flood waters to be let out gradually and used for irrigation purposes. This plan would undoubtedly be physically practicable, provided that the dams were so constructed as to be absolutely safe in case of any floods that might occur. There are, however, a number of legal complications that it would be difficult to overcome. For example, there is the case of Castlewood Reservoir, already mentioned. This reservoir receives the drainage from about 175 square miles out of a total of 404 square miles above the city limits. Unless this reservoir and irrigation system were acquired, or were used in co-operation with those reservoirs to be constructed above, it would be impracticable to hold back waters to which the Castlewood Reservoir was entitled, at least until it had been determined that the claims of the Castlewood Reservoir and irrigation system were satisfied, in which event all the flood waters would generally have passed the upper reservoirs. In all cases, moreover, there would be the difficulties already referred to as to the storage of water which might or might not be needed by prior appropriators along the South Platte River. Many instances have occurred in the State of Colorado where waters thus impounded had been turned down the stream later by the state authorities to satisfy the claims of prior appropriators. So far as the irrigation feature of the proposition is concerned, therefore, the Commission believes it to have little merit. Undoubtedly, however, a series of reservoirs could be constructed that would answer the purpose, provided it is understood that the water was not to be used by new appropriators, but was to be turned down at such times and in such quantities as might be ordered by the state authorities for the benefit of prior appropriators. The cost of constructing a considerable number of safe dams would, however, exceed the cost of constructing a single dam capable of taking care of any entire flood that might come; and, furthermore, in constructing works to last for indefinitely long periods of time, consideration should be given to the silt problem. It is well known that, even when there is but a small amount of water coming down Cherry Creek, there is a considerable amount of sand and gravel traveling along the bed of the stream, and when floods occur, the water is so heavily charged with silt and sand that the lives of small reservoirs used

for impounding water would necessarily be short, as compared with the life of such a city as Denver. This subject has been considered and passed upon in many different places, and it is almost invariably found that the plan of having a large number of small reservoirs constructed is not so economical and efficient as the method of constructing one large reservoir sufficient for all requirements. There is, in this case, the additional objection to be considered that, if one or more of the small reservoirs should break, the flood at Denver might be much more disastrous than would be the case if no attempt had been made to regulate the flow. No detailed survey has been made of this plan by the Commission, on account of lack of time and funds, and for the additional reason that the Commission believes that the construction of a large reservoir would be more advantageous than the construction of a number of smaller ones.

XI. THE CONSTRUCTION OF A NUMBER OF SMALL REGULATING DAMS

This plan is similar to Plan No. X, excepting that in this case it is not proposed that the water shall be stored for irrigation purposes, but rather that the dams shall act simply as regulators, allowing only such amounts of water to pass as would not endanger the lowlands of the city. This might be done by means of outlets capable of discharging only a predetermined amount of water, or by means of valves controlled by caretakers located at the respective dams. This plan, again, is not favored by the Commission, for the reasons stated in some of the preceding cases.

XII. REGULATING DAMS AND CONCRETE CONDUIT

This plan would involve practically the construction of a series of regulating dams, as proposed in Plan No. XI, with the addition of a concrete conduit capable of carrying any predetermined amount, as, for example, 10,000 cubic feet per second through the city. This conduit could be used practically as a great storm or combination sewer. It is argued in its favor that the channel of Cherry Creek could then be done away with completely, and the ground used either for park and driveway purposes, or even as residence or business property, thus creating a great asset to the city. This plan appears to the Commission to involve two separate propositions: first, that of the regulation of the flow of water to some predetermined amount, and, second, that of the construction of such a storm sewer or underground waterway as is proposed. The problem, therefore, of the regula-

tion of the flow must first be determined, after which the construction of such a waterway might be taken up as a separate proposition, to be determined at some future time. It would obviously be impracticable to build such a waterway sufficiently large to carry all of the water that it is thought might possibly come down the creek at the time of maximum flood without regulation.

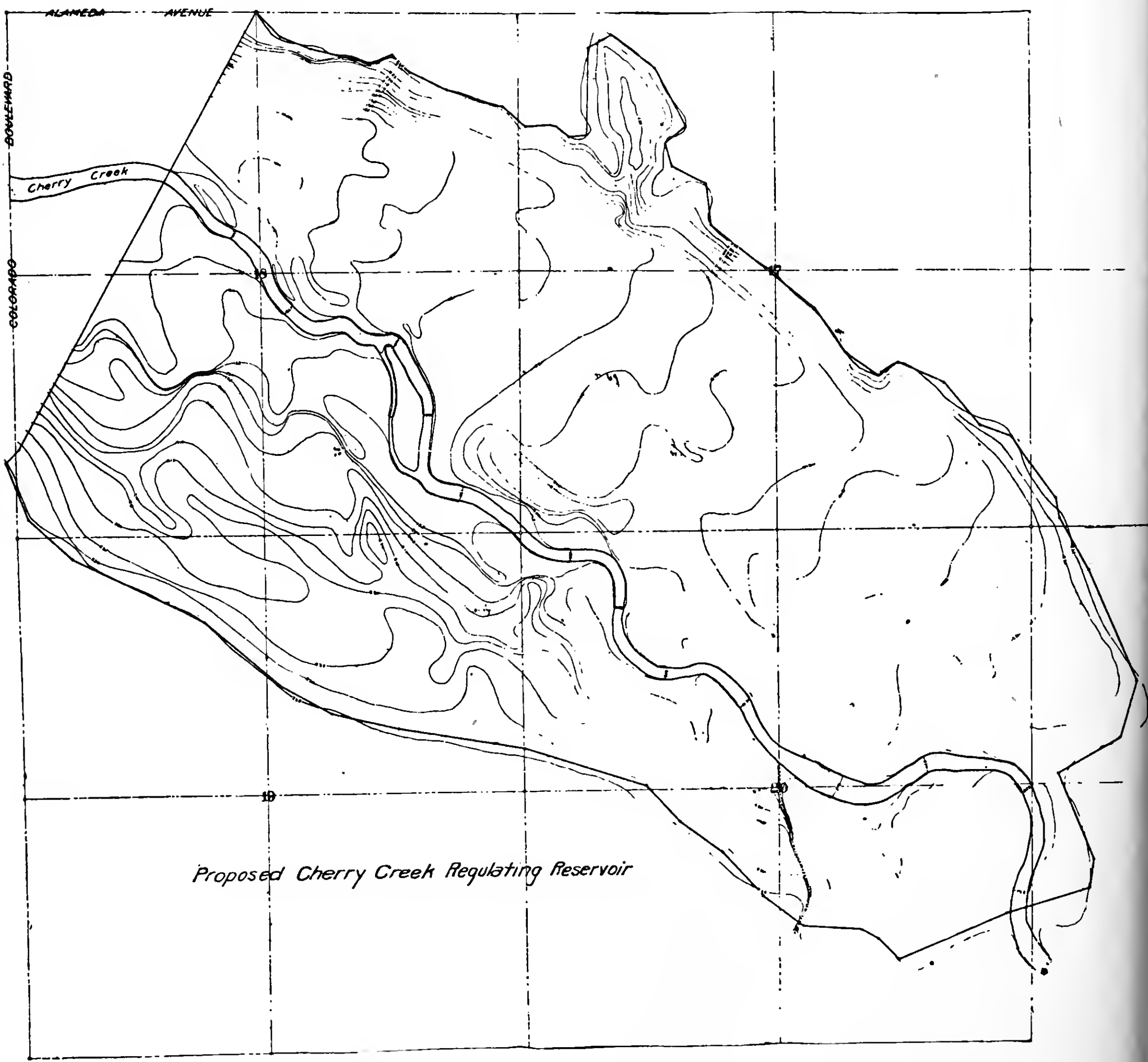
XIII. A SINGLE REGULATING RESERVOIR

This plan contemplates the construction of a dam at some point on Cherry Creek near or above the eastern city limits, capable of creating a reservoir sufficiently large to control any flood that could possibly be anticipated. The Flood Commission has examined and caused to be surveyed two such sites, one just above the city limits and the other some distance, about four miles, farther up-stream. The one nearest the city limits is the only one here discussed, as it is believed by the Commission to be the more practicable one of the two. A plat of the proposed reservoir is shown herewith, together with details as to the depth to bed-rock, profile of the dam site, etc. A table is also given herewith, showing the area and capacity of the proposed regulating reservoir, at different depths, referred both to the city datum and to sea-level elevations:

TABLE SHOWING AREA AND CAPACITY OF PROPOSED REGULATING RESERVOIR

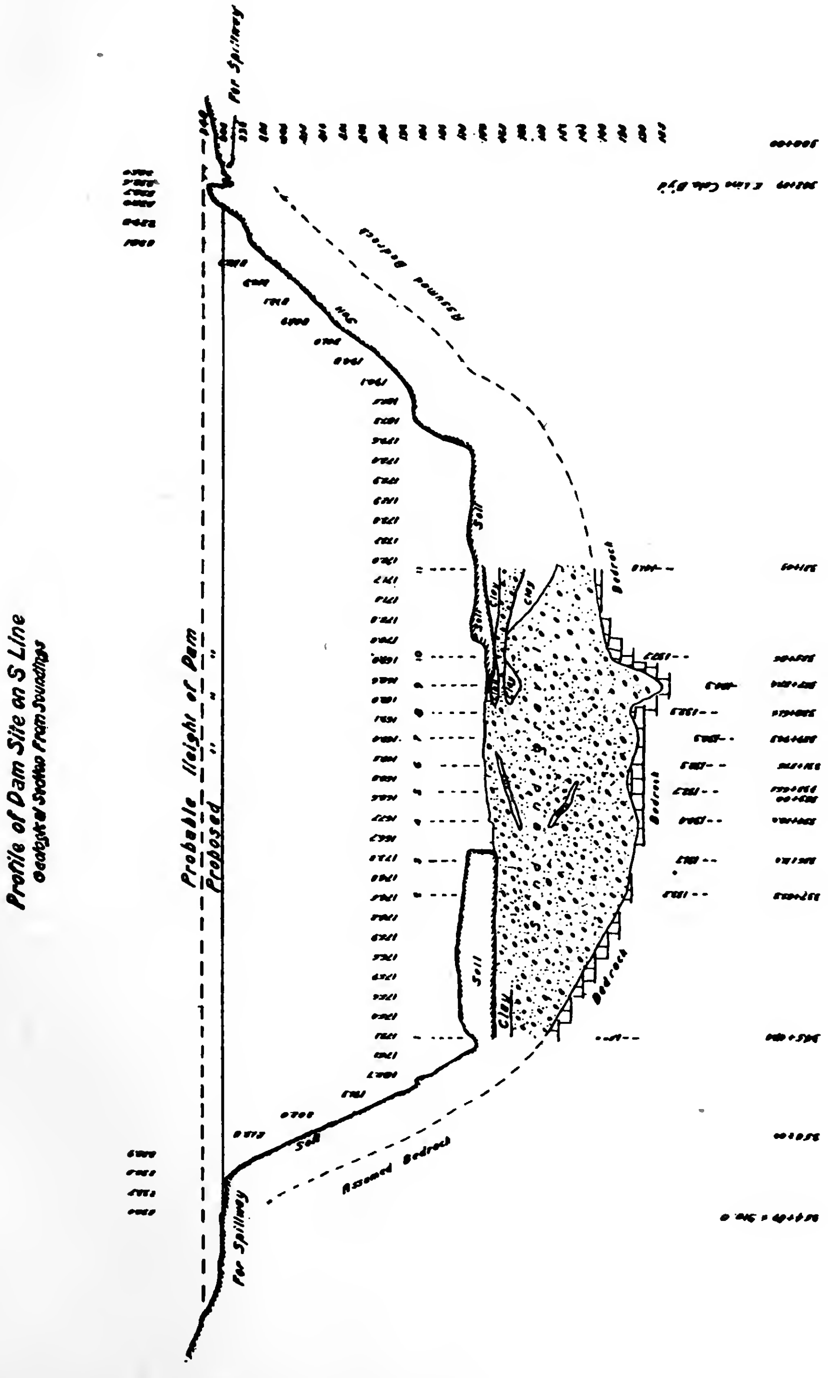
Elevation of Contours	Area in Sq. Ft. for Each 5-Ft. Contour	Capacity in Cu. Ft. Mean	Cu. Ft. for Each 5-Ft. Contour	Total Cu. Ft.	Capacity in Acre-Ft.
168 city datum..	....	....	....	....	....
5,342 sea-level....	....	....	....	....	....
170 city datum..	....	224,000 x 2	448,000	....	....
5,347 sea-level....	448,000	....	....	448,000	10.28
175 city datum..	....	1,120,000 x 5	5,600,000	....	....
5,352 sea-level....	1,792,000	....	....	6,048,000	138.84
180 city datum..	....	3,424,000 x 5	17,120,000	....	....
5,357 sea-level....	5,056,000	....	....	23,168,000	531.86
185 city datum..	....	6,216,000 x 5	31,080,000	....	....
5,362 sea-level....	7,376,000	....	....	54,248,000	1,245.36
190 city datum..	....	9,344,000 x 5	46,720,000	....	....
5,367 sea-level....	11,312,000	....	....	100,968,000	2,317.90
195 city datum..	....	13,640,000 x 5	68,200,000	....	....
5,372 sea-level....	15,968,000	....	....	169,168,000	3,883.56
200 city datum..	....	17,722,000 x 5	88,610,000	....	....
5,377 sea-level....	19,520,000	....	....	257,778,000	5,917.77
205 city datum..	....	21,880,000 x 5	109,400,000	....	....
5,382 sea-level....	24,240,000	....	....	367,178,000	8,429.24
210 city datum..	....	27,376,000 x 5	136,880,000	....	....
5,387 sea-level....	30,512,000	....	....	504,058,000	11,571.58
215 city datum..	....	33,224,000 x 5	166,120,000	....	....
5,392 sea-level....	35,936,000	....	....	670,178,000	15,614.74
220 city datum..	....	39,144,000 x 5	195,720,000	....	....
5,397 sea-level....	42,352,000	....	....	865,898,000	19,878.28
225 city datum..	....	45,272,000 x 5	226,360,000	....	....
5,402 sea-level....	48,192,000	....	....	1,092,258,000	25,492.79
230 city datum..	....	52,508,000 x 5	262,540,000	....	....
5,407 sea-level....	56,824,000	....	....	1,354,798,000	31,101.88
235 city datum..	....	60,324,000 x 5	301,620,000	....	....
5,412 sea-level....	63,824,000	....	....	1,656,418,000	38,026.12

As may be seen from the foregoing table, when the water in the reservoir was twelve feet in depth at the outlet, the reservoir would be impounding approximately 500 acre-feet of water; with the water twenty-two feet in depth at the outlet, it would be impounding approximately 2,300 acre-feet; with the water thirty-two feet in depth, it would be impounding approximately 6,000 acre-feet; with the water sixty-two feet in depth, it would be holding back over 31,000 acre-feet. The capacity could be increased up to approximately 40,000 acre-feet. This plan, however, does not contemplate holding back any water, excepting as it may be necessary to regulate the flow so as to permit of the passage through the city of only such an amount as it would be entirely safe to pass through Cherry Creek channel in addition to any local supply that might be entering it. The Commission in this



Proposed Cherry Creek Regulating Reservoir

discussion has estimated that with the Cherry Creek channel in a proper condition, as is contemplated, 10,000 cubic feet per second might be safely allowed to pass the eastern city limits at any time, unless there were such a flood in South Platte River as would make it inadvisable temporarily to turn so large an amount down Cherry Creek, in which case the amount permitted to cross the eastern city limits might be decreased by means of regulating gates in the dam. For the purpose of illustrating what would occur in case this plan were to be carried out, the



flood of July 14, 1912, may be taken as an example. Assuming that the Cherry Creek channel throughout the city were put in proper condition, as has been already recommended by the Flood Commission, by the completion of Cherry Creek walls on the basis now outlined, from the South Platte River to the eastern city limit, or even, temporarily, to Downing Street; and assuming, further, that the total discharge of the flood amounted to 4,000 acre-feet, and that the outlet to the reservoir would discharge approximately 5,000 cubic feet per second, without checking the water materially, and that the discharge was susceptible to regulation, there might have been some such condition of affairs as is shown by the following table, illustrating the possible conditions:

TABLE ILLUSTRATING POSSIBLE REGULATION BY PROPOSED RESERVOIR OF A 4,000 ACRE-FOOT FLOOD WITH A MAXIMUM FLOW FOR ONE-HALF HOUR OF 25,000 SECOND-FEET

Time by Half-Hours	Flood Discharge In Second-Ft.	Flood Discharge In Acre-Ft.	Total Acre-Ft. at End of Half-Hour Period	Second-Ft. Discharged from Reservoir	Acre-Ft. Held in Reservoir at End of Half-Hour	Depth in Reservoir
First	5,000	208	208	5,000	0	0
Second	10,000	416	624	6,000	168	8
Third	25,000	1,040	1,664	7,000	918	14
Fourth	20,000	832	2,496	8,000	1,418	18
Fifth	15,000	624	3,120	9,000	1,668	19
Sixth	10,000	416	3,536	10,000	1,668	19
Seventh	10,000	416	3,952	10,000	1,668	19
Eighth	5,000	208	4,160	10,000	1,460	18
Ninth	0	....	....	10,000	1,044	16
Tenth	....	....	....	10,000	628	13
Eleventh	....	....	....	10,000	212	8
Twelfth	....	....	....	5,000	4	0

Examination of this table shows that, under the conditions assumed, the total 4,160 acre-feet of water would have passed the eastern city limits within four hours, with a maximum discharge of 25,000 cubic feet per second. With a regulating reservoir, controlled as shown in the table, it would have required six hours for all of the water to be discharged through the city, with a maximum discharge of 10,000 cubic feet per second, lasting for three hours. The maximum depth in the reservoir would have been nineteen feet, and at the end of six hours the reservoir would have been completely drained. Of course, these conditions might be modified to any extent desired, but the example will serve to illustrate the possibilities of the plan. For the purpose of regulating a flood coming in the manner shown in the table, therefore, a capacity of 1,668 acre-feet would be necessary, requiring a depth of nineteen feet, to which should be added for safety at least ten feet, making the dam twenty-nine feet in height, if no provision were to be made for an overflow weir.

As has already been shown in the discussion of the possible run-off, a storm of much greater magnitude, or a series of storms, might occur which would require either greater capacity in the reservoir for the regulation of the flow, or a spillway, or weir, for the purpose of discharging into the stream any amount of water that could not be carried through conduits. It is obvious that the water discharged from such a spillway or weir would have to be added to the flow in the stream, and would increase the discharge below, unless the amount were cut off at the regulating gates.

For the purpose of illustrating what might be required for such a flood as has been deemed possible, the following table has been compiled:

TABLE ILLUSTRATING POSSIBLE REGULATION BY PROPOSED RESERVOIR OF A 12,644 ACRE-FOOT FLOOD WITH A MAXIMUM FLOW FOR ONE-HALF HOUR OF 60,000 SECOND-FEET

Time by Half-Hours	Flood Discharge In Second-Ft.	Flood Discharge In Acre-Ft.	Total Acre-Ft. at End of Half-Hour Period	Second-Ft. Discharged from Reservoir	Acre-Ft. Held in Reservoir at End of Half-Hour Period	Depth in Reservoir
First	20,000	832	832	5,000	624	13
Second	40,000	1,664	2,496	10,000	1,872	20
Third	60,000	2,496	5,992	10,000	3,952	27
Fourth	50,000	2,080	8,072	10,000	5,618	32
Fifth	40,000	1,664	9,736	10,000	6,864	34
Sixth	30,000	1,248	11,084	10,000	7,696	35
Seventh	20,000	832	11,916	10,000	8,112	36
Eighth	10,000	416	12,332	10,000	8,112	36
Ninth	5,000	208	12,540	10,000	7,904	36
Tenth	2,500	104	12,644	10,000	7,692	35
Eleventh	0	0	12,644	10,000	7,276	35
Twelfth	....	....	....	10,000	6,860	34
Thirteenth ...	....	....	....	10,000	6,444	33
Fourteenth ...	....	....	....	10,000	6,028	32
Fifteenth	....	....	....	10,000	5,614	31
Sixteenth	....	....	....	10,000	5,198	30
Seventeenth ..	....	....	....	10,000	4,782	29
Eighteenth ...	....	....	....	10,000	4,366	28
Nineteenth ...	....	....	....	10,000	3,950	27
Twentieth	....	....	....	10,000	3,534	26
Twenty-first .	....	....	....	10,000	3,118	25
Twenty-second	....	....	....	10,000	2,702	23
Twenty-third .	....	....	....	10,000	2,286	22
Twenty-fourth	....	....	....	10,000	1,870	20
Twenty-fifth .	....	....	....	10,000	1,454	18
Twenty-sixth .	....	....	....	10,000	1,038	16
Twenty-seventh	....	....	....	10,000	622	12
Twenty-eighth	....	....	....	7,500	310	9
Twenty-ninth	....	....	....	5,000	102	7
Thirtieth	....	....	....	2,500	0	0

The conditions assumed for the foregoing table are more severe than are considered at all probable, and yet they are believed to be possible. A flood with a maximum flow for a full half-hour of 60,000 cubic feet per second is assumed, this amount arriving at the reservoir in the third half-hour period and decreasing gradually until, at the end of five hours, the flood is assumed to have entirely passed. As a matter of fact, no such flood would

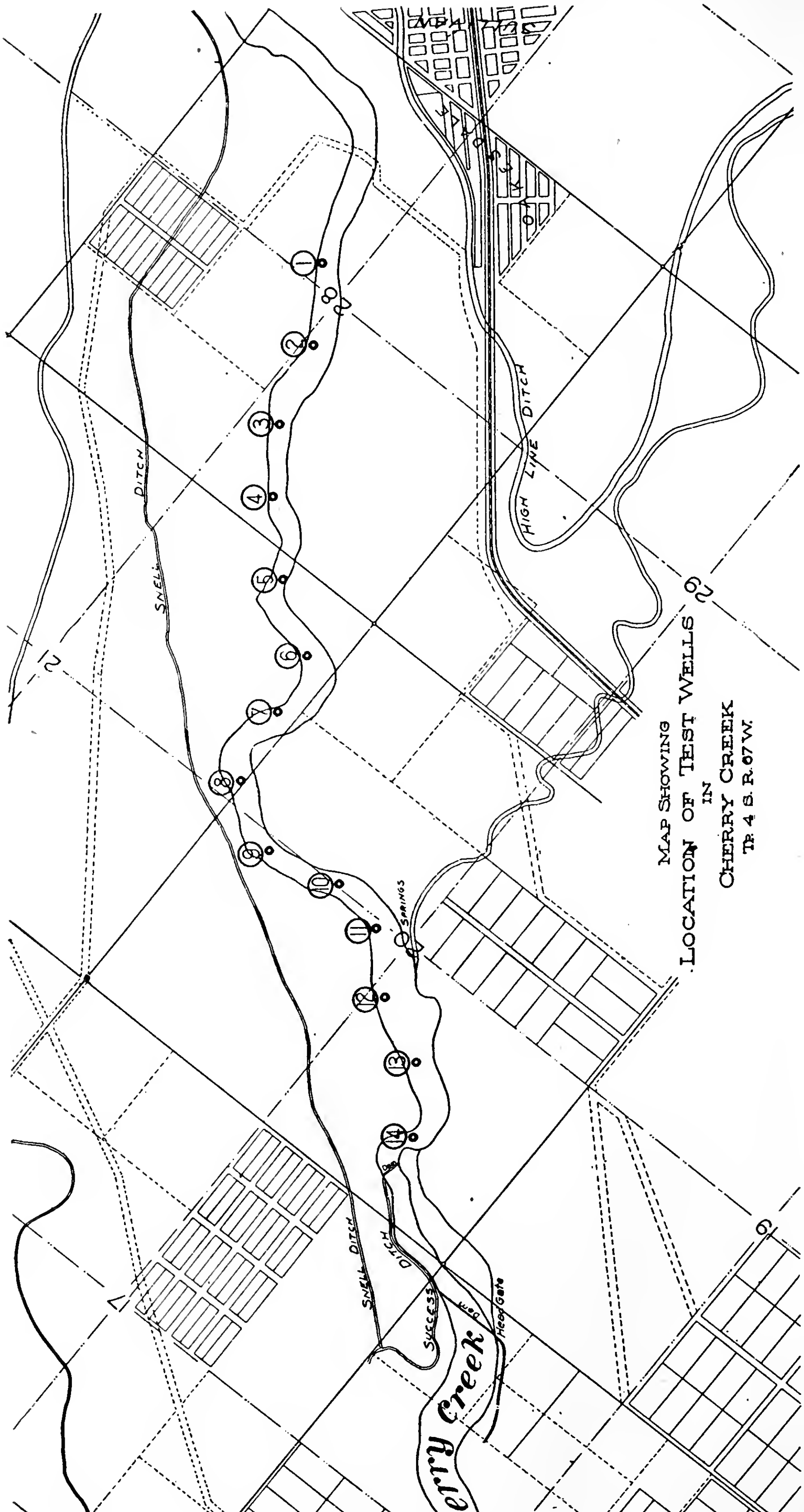
pass away so soon, but this fact is immaterial, as a more protracted flow would simply mean a similar increase in time in emptying the reservoir. Under the conditions assumed, therefore, with a maximum flow of 60,000 cubic feet per second during the third half-hour period, we should have thirty-six feet of water in the reservoir at the end of the seventh half-hour period; this stage continuing until the end of the ninth half-hour period, after which it would be drawn off gradually, until at the end of the thirtieth half-hour period, or fifteen hours, the water would all be gone from the reservoir, the channel carrying a constant flow of 10,000 cubic feet per second for approximately fourteen hours. Of course, this result would have to be obtained by regulation of the gates, and the gates might be so regulated, if desired, that the amount passing down the channel would be either very materially increased or decreased, as might seem to be desirable. For example, if, as would be likely to be the case, a great flood were being discharged in the South Platte River at the same time, thus decreasing the hydraulic gradient of Cherry Creek, it might be desirable to shut off practically the entire discharge from the reservoir until the South Platte flood had passed, after which it is obvious that the water held back in the Cherry Creek reservoir would be drawn off in from about ten hours up to as long a period as might seem desirable. It is also obvious that, if the entire amount were to be retained in the reservoir, no water whatsoever being allowed to discharge, the crest reached would be approximately forty-three feet. This condition of affairs would, however, probably never prevail, as the water should always be allowed to discharge from the reservoir as rapidly as was practicable.

The Silt Problem.—It has been argued by some that this plan would prove to be impracticable on account of the great amount of silt contained by the waters of Cherry Creek at flood stages. It is pointed out that considerable proportions of the volume of the water are made up of silt, sand, gravel, etc., and that the reservoir capacity would rapidly diminish through the settling of the sediment in the water, and that sooner or later the efficiency of the reservoir would be destroyed in this way. Careful study of the situation, however, leads to the conclusion that this fear is practically groundless. The plain purpose of the reservoir would be simply the regulation of great floods and not their retention. For this reason, all minor floods having a discharge up to at least 5,000 cubic feet per second would not allow the possibility of

depositing the sediment. As floods of this size constitute practically all of the floods occurring in the Cherry Creek drainage basin, with the exception of an occasional flood occurring at irregular intervals of from ten to twenty years, it is obvious that a channel could be maintained through the reservoir, which would be kept scoured out practically as it is now the greater part of the time. Upon the occurrence of a great flood, it is obvious that the heavier materials carried by the water would be deposited along the line of the channel as the water rose in the reservoir. The finer materials, including the silt, would be, for the most part, held in suspension by the water until it had been discharged from the reservoir, leaving beds along the channel of comparatively clean sand and gravel, which could be used advantageously for building purposes and for the construction of roads. Indeed, the Flood Commission believes that this sand and gravel would in time be a valuable asset to the city, rather than a detriment. In any case, it would be of comparatively little importance, as will be seen by closer examination of statistics and records.

It is believed that within the life of the city of Denver, approximately fifty-five years, there have been but three floods which would have deposited any material whatsoever within the reservoir site. It is not likely that more than 5 per cent by volume of the water passing through the reservoir would have been deposited, even under the worst conditions. If it is assumed that each of these floods brought down 4,000 acre-feet, or 12,000 acre-feet for the three floods, it appears that but 600 acre-feet of sand and gravel, on the basis of 5 per cent, would have been deposited in fifty-five years in the reservoir site. With the Denver of today and the Denver of the future there would be such a demand for this comparatively small amount of sand and gravel that there would be no trouble whatsoever in using all of it beneficially.

If it be assumed, again, that a 60,000-cubic-foot-per-second flood should occur, with a total discharge of 12,000 acre-feet, it is obvious that, even if 5 per cent by volume of the water were to be deposited in the reservoir, only about 600 acre-feet would be deposited for such a flood, and if these floods occur, on the average, but once in a hundred years, together with six floods of the size of that of July 14, 1912, we should have a total deposit in the reservoir in the hundred-year period of only 1,800 acre-feet of sand and gravel, for all of which there would be a demand. Even if it were not used, however, and the assumptions here made should

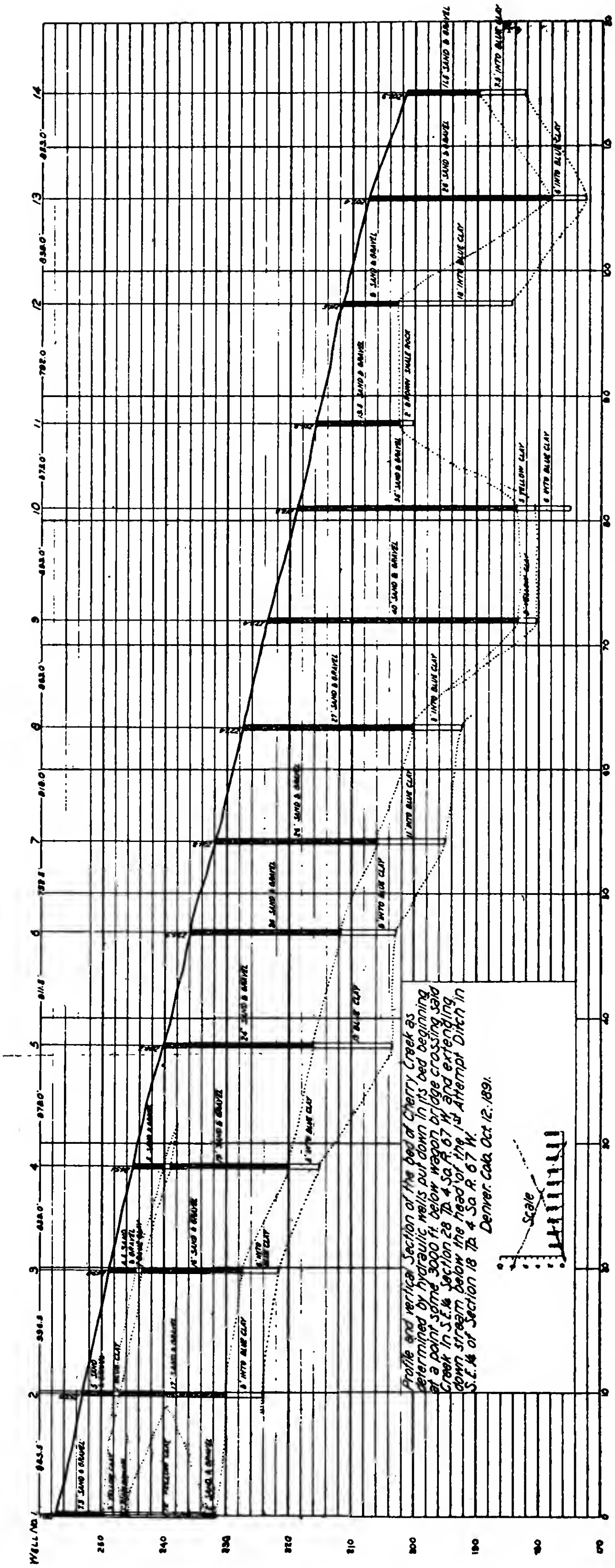

Map Showing
Location of Test Wells
in
Cherry Creek
Tp. 4 S. R. 67 W.
Cherry Creek
Snell Ditch
High Line Ditch
Success Ditch
Head Gate
Springs
1
2
3
4
5
6
7
8
9
10
11
12
13
14
29
28
21
17
9

hold indefinitely, and if none of the material deposited by these great floods were washed out (which, by the way, is not tenable), there would be deposited in a thousand years only 18,000 acre-feet of sediment, or enough to require an increase in the depth of the reservoir from approximately forty feet to approximately sixty feet, to take care of even the 60,000-cubic-feet-per-second floods of that day and generation. How much such a reservoir would save the city cannot be estimated, but certainly it would save many times the cost of the dam and controlling works upon the occurrence of a single flood of the magnitude which has been assumed to be possible, or even of a flood not much larger than that of July 14, 1912.

As there are other reservoir sites higher up on the stream which could be used to almost as great advantage as the one under discussion, it is clear that by the construction of the reservoir proposed, followed by the raising of this reservoir dam, or the construction of other reservoirs at intervals of a thousand or more years apart, the safety of the city could be secured for an indefinite length of time.

The Drift Problem.—The problem of floating logs, stumps, timber, etc., would be completely solved by the construction of such a reservoir as is proposed, as grillage would be constructed above the openings of the conduits in such a way as to catch practically all such floating debris of any consequence and hold it in the reservoir, without diminishing the discharge through the gates. This would at once remove one of the most serious menaces to allowing water to flow unimpeded down Cherry Creek channel, as, in the past, it has been through the construction of dams composed of this floating material lodging against bridges that the greatest damages have occurred. Much of this drift, collected at the dam, would have sufficient value to make it worth hauling it away to a municipal lumber yard, or for use for other purposes, and any considerable amount of worthless material could readily be burned, so that no considerable amount would collect at the dam site. In this way freedom from the construction of such dams as have been formed in the past at bridges within the city would be reasonably assured.

Use of Lands within the Reservoir Site.—Land within the reservoir site would have to be acquired by the city. The city is given power by its charter to acquire such property, and there seems to be no good reason why the land thus acquired might not


Profile and vertical Section of the bed of Cherry Creek as determined by hydraulic wells put down in its bed beginning at a point some 3000 ft. below wagon bridge crossing said Creek in S.E.¼ Section 28 Tp. 4 So. R. 67 W. and extending down stream below the head of the 1st Attempt Ditch in S.E.¼ of Section 18 Tp. 4 So. R. 67 W.
Denver. Colo. Oct 12. 1891.
Scale
Well No. 1

be used to some extent for the raising of crops, if this were desired. Obviously no buildings or settlement of any kind could be permitted in the reservoir site, but it would be entirely practicable for the lands to be farmed—subject, of course, to possibility of loss by submersion. The risk, however, would be very slight, as the submersion of the lands for a few hours would not injure most growing crops.

Another use to which the lands might be put would be for park purposes. Within a comparatively short period of time Denver will undoubtedly be looking for other parks, and such a tract of land as is contained in the proposed reservoir site could be used advantageously as a suburban park, with lawns, trees, and graveled drives, none of which, if properly selected, would be seriously injured by any submergence that could occur.

Development of Water Supply.—In the construction of the proposed dam it would be necessary either to construct a cut-off wall across the Cherry Creek valley or to drive sheet piling across the bed of the stream. In either case a certain amount of underflow would be developed. No investigations have been made as to the amount, but the members of the Commission believe that possibly a flow of twenty-five cubic feet per second might be made available for the city's use. This water might be used either locally for the irrigation of the park or for the city's domestic water supply. There would also be acquired certain water rights in connection with the purchase of the lands. These water rights would be among the best and most valuable on Cherry Creek and would be of considerable value, in the future, to the city. It is difficult to estimate at all closely what the water, both developed and purchased, would be worth to the city, but the Flood Commission believes that it would amount, in all probability, to at least $200,000.

XIV. THE CONSTRUCTION OF A SMALL REGULATING RESERVOIR

This plan is similar to Plan No. XIII, and the general discussion regarding Plan No. XIII is applicable to this one also. This plan differs from the preceding, however, in that it is proposed that the capacity of the reservoir shall be relatively small, capable of regulating such floods as have been known to occur in the history of the city, and providing a spillway over which unprecedented floods, such as are suggested as possible, might pass, after the full capacity of the reservoir had been reached. As shown by the tables given under the preceding plan, a reservoir

having a spillway at an elevation of about twenty feet above the bottom of the outlet would be required, embankments connecting with this spillway being raised sufficiently high to preclude the possibility of their being overtopped by any flood. With a channel safely carrying not less than 10,000 cubic feet per second through the city, it seems reasonably certain that any flood that has ever occurred within the history of the city would be regulated; while greater floods would pour their surplus over the spillway as soon as the capacity of the reservoir had been reached. The drift would, however, be checked as in the preceding case, even for the highest floods, by means of suitable grillage. This plan would have the important advantage of greatly decreased cost over the preceding plan. It would, however, have the disadvantage that it would not surely safeguard the city against the possible maximum flood, although it would greatly decrease the damages ensuing from such a flood.

If it were assumed, for example, that such a great flood as is suggested, having a 60,000-cubic-foot-per-second flow, should occur, it will be seen, by glancing at the table given for that flood, that the reservoir would have been full at the end of the second half-hour. Consequently, after the end of the second half-hour period the outflow would be the sum of the 10,000 second-feet passing through the gates and whatever was passing over the weir. It is obvious, therefore, that such a reservoir would be of little value, if such a maximum flood should occur. For all cases known in the past, however, it would seem that such a reservoir should give satisfaction.

XV. THE CONSTRUCTION OF A REGULATING RESERVOIR OF MAXIMUM SIZE

This plan contemplates the construction of a regulating reservoir sufficiently large to control waters of any flood considered possible. The only difference between this and Plan No. XIII is that this one contemplates the building of the proposed reservoir to its maximum capacity, while Plan No. XIII provides for the construction of a reservoir of less capacity, but still of a size deemed large enough to protect the city under almost any emergency that may arise. As has been already stated, it is practically impossible to discuss one of these plans without discussing all of them, and nearly all that has been said regarding Plan No. XIII is applicable to this one also. This, however, would be much more expensive than Plan No. XIII. It would be necessary

in this case to build the dam to a height of approximately seventy-five feet, with a spillway at about sixty-five feet. With the construction of such a reservoir it would become possible to hold back approximately 40,000 acre-feet of water, which would allow for a much more severe storm, or series of storms, than is contemplated in the preceding discussion.

SUMMARY

It will be seen upon examination that the first four of the plans described contemplate using the present channel, either as now, in part, constructed, or with paving, increasing the height of the walls or the width of the channel, or both, or by the construction of a second channel beside the first one—all without the construction of reservoirs or other means of regulation. Plans V, VI, and VII contemplate diversion channels with a view simply to diverting flood waters from Cherry Creek to the South Platte River by other routes than that now occupied. Plans VIII and IX contemplate the diversion of these flood waters for irrigation purposes through the construction of storage reservoirs located at points more or less distant from the Cherry Creek channel. Plans X and XI provide for the construction of a number of reservoirs or regulating dams along Cherry Creek and its tributaries. Plan No. XII provides for both regulation and subsequent construction of a concrete conduit to be used as a sewer. Plans XIII, XIV, and XV contemplate the construction of a reservoir of greater or less capacity practically at the eastern city boundary.

The Commission has attempted to give, from an unprejudiced standpoint, the arguments for and against the various plans. After comparing all the plans, it is not favorably disposed toward the first four, without regulation, as they do not appear to meet all conditions that may arise. It does not favor plans for the diversion of the floods, for reasons that have already been given in sufficient detail. After studying all the different methods, the Flood Commission has come to the conclusion that the best method of controlling the situation, and eliminating the dangers to the greatest possible extent, is by the construction of a single large reservoir rather than a number of small ones, for reasons given above, but which may be summarized as follows: A single large reservoir would be more efficient, safer, and under better control than a number of small reservoirs, and it is believed that,

when due consideration is given to safety, the large reservoir will cost less money than the smaller ones.

As to the best plan to be adopted for regulation of the floods, it may be said that there are strong arguments in favor of each method described. A comparatively small reservoir, capable of taking care of any known flood up to the present time, would be of very moderate cost. The Commission believes that such a dam and regulating reservoir would fully protect the city against any flood as large as the largest that has occurred within the last fifty-five years. It is convinced, however, that floods may occur of such magnitude that damages aggregating perhaps many millions of dollars, accompanied by the loss of many lives, would result, and it believes, therefore, that it would be wise for the city to provide against such a casualty by the construction of a larger reservoir. On the other hand, it would be easily possible to carry such precautionary measures to an extreme, resulting in much greater cost to the city than is necessary. The construction of a reservoir of the maximum size, as suggested in Plan No. XV, would provide against floods much more serious in character than the Commission believes to be at all probable. The construction of a reservoir of the size suggested in Plan No. XIII, however, would seem to meet all contingencies that could reasonably be anticipated. Such a reservoir could be constructed with a grillage that would prevent any drift from passing on down the stream, with outlets capable of discharging 10,000 cubic feet per second, with a head of fifteen feet, with gates capable of regulating the discharge to as great an extent as might be deemed necessary, with a spillway capable of safeguarding the dam in case a flood even larger than the flood suggested as the maximum should occur, and constructed in such a way as to be permanent, and yet susceptible of enlargement should it ever be deemed necessary.

In accordance with the foregoing considerations, the Commission has adopted plans for a reservoir with a capacity of approximately 12,000 acre-feet, necessitating a dam with a spillway approximately forty-two feet above the bottom of the outlet chambers, the spillway occupying approximately 200 feet of the length of the dam, with wingwalls of concrete, behind which and extending for the entire length of the dam, with the exception of the spillway and wingwalls, would be an embankment of earth with a crest elevation of ten feet above the crest of the spillway. This dam would be so constructed as to permit of its being increased in height whenever this might appear desirable.

The Commission has made a careful study of the cost of dams as nearly similar as practicable to the dam proposed, and has also made estimates based upon preliminary plans of several different types. As the result of its studies and investigations, it has concluded that a dam that will meet all requirements and emergencies can be erected for less than $500,000 for construction and an equal amount for the lands; and as the outlay of much more time and money would be required for the preparation of detail plans than can possibly be given by the Commission at this time, and as any constructing board of engineers would undoubtedly insist on making its own detail plans and specifications, it has been decided to adopt, as an approximate estimate of the entire cost of the proposed dam, the sum of $1,000,000.

CONCLUSIONS

In stating its conclusions, the Flood Commission feels that it should again express its regret that it is impracticable for it to make a complete and detailed report under the existing conditions. To a great extent, all that has been said regarding the Cherry Creek water-shed is applicable to the South Platte water-shed also. This stream, however, is already reaching a more or less satisfactory stage of flood regulation. The Commission believes that this stream also should be walled, and that regulating reservoirs should be constructed on some of the branches of the South Platte that are not now regulated, particularly the North Fork of the South Platte, Bear Creek, and Plum Creek. The Commission, however, has been unable to study these streams in detail, but it believes that precautionary methods ought to be taken regarding them, similar to those recommended to be taken regarding Cherry Creek. In particular, the Commission would call attention to the fact that many of the bridges across South Platte are pile bridges, endangering portions of the city, as the pile bridges on Cherry Creek are described as endangering the lands of the Cherry Creek valley.

Regarding Cherry Creek, the Commission believes that floods may be regulated with comparative ease, if proper methods are adopted. In this connection it would call attention to the brief discussion given in the appendix, of plans of regulation adopted elsewhere, and particularly to the report of the Pittsburg Flood Commission—a report prepared in great detail and at an expense

of approximately $125,000, with a view to regulating the floods on the tributaries of the Ohio River. A careful study of this report will convince even the most skeptical that flood regulation by construction of regulating reservoirs has been used with complete success, both in this country and in foreign countries.

After its study of Cherry Creek situation, the Commission has come to the following conclusions:

1. Conditions on Cherry Creek are such that floods as great as those that have already occurred appear to be certain, while very much larger floods may be expected.

2. A flood with a maximum discharge of 60,000 cubic feet per second, lasting for a short time, is considered as not only possible, but even probable.

3. Damages resulting from great floods of equal volume must necessarily increase with the growth of the city, unless proper control is provided.

4. Direct losses in the past resulting from floods have aggregated hundreds of thousands of dollars, with the loss of some lives.

5. Losses by floods in the future cannot be estimated even approximately, but are certain to amount to millions of dollars and the loss of many lives, if remedial plans are not adopted.

6. Flood losses in other portions of the valley of the South Platte and Cherry Creek districts, both of vital importance to Denver, will become more and more serious as property becomes more valuable.

7. Relief through other methods than regulation by reservoirs is not recommended, for the reasons that such methods would give local relief only, that increase in size of the present channel for diversion would prove inefficient, or else that the construction of sufficiently effective channel and walls would prove to be too costly.

8. It is entirely feasible to regulate the flood waters by the construction of one or more regulating reservoirs.

9. Favorable reservoir sites of sufficient capacity to regulate the floods of Cherry Creek exist within reasonable distances above the city limits.

10. One reservoir site of sufficient capacity, and fulfilling all essential requisites, has been selected.

11. The reservoir site selected is capable of furnishing all the protection required, when the channel is put in good condition, as recommended.

12. If this reservoir had been constructed, and the channel had been properly cleared of obstructions, at the time of the flood of July 14, 1912, no damages would have resulted.

13. To supplement the construction of a regulating reservoir, the channel through the city should be made efficient by the completion of the walls, and removal of pile bridges and other obstructions, and such work as would be necessary to make the stream capable of carrying from 10,000 to 12,000 cubic feet per second without endangering the city.

14. Flood prevention by storage reservoirs is possible and practicable, and is recommended, because:

(a) Flood relief would benefit residents in the South Platte valley as well as in the city of Denver.

(b) The regulated supply would be more easily diverted and controlled for irrigation and other beneficial uses than would be the case with unregulated flood flows.

(c) Public health would be safeguarded against dangers arising from the unsanitary conditions caused by overflow.

(d) A properly constructed regulating reservoir would appear to satisfy all conditions.

15. Regulating reservoirs have been built in other countries with such success in preventing floods that other large works of this kind are now under construction and many more are contemplated.

16. Regulation of Cherry Creek floods by regulating reservoirs has been pronounced practicable by a number of eminent engineers to whom the problem has been submitted.

17. The estimates of cost of regulating reservoirs, while of more or less preliminary nature, are believed to be conservative and show that Denver may be completely protected against floods at a cost of not more than one million dollars.

18. The construction of the proposed regulating reservoirs and the control of the floods are urged for the following reasons:

(a) Had such a reservoir been constructed at the times of the occurrence of the great floods in the history of the city, losses aggregating at least hundreds of thousands of dollars would have been saved.

(b) It would insure protection against damages aggregating in the future many times the cost of the reservoir, as well as result in the saving of lives.

(c) It would increase the value of property along the Cherry Creek valley in the city of Denver, and in the lowlands along the South Platte, to much more than the cost of the regulating reservoirs.

(d) The cost is small when the total property loss by flood damage within the next few years in all districts that would receive benefit, is considered.

(e) The value of the water acquired by the city would go far toward compensating for the cost of the reservoir.

(f) The value of the proposed reservoir as a park site is material and should have due weight.

All things being considered, therefore, the Commission concludes that the construction of a regulating reservoir above Denver is the most logical plan that can be adopted.

RECOMMENDATIONS

In view of the foregoing considerations and conclusions, the Flood Commission makes the following recommendations:

1. The channel of Cherry Creek within the city limits, where not yet acquired by the city, should be acquired as soon as possible.

2. The work on Cherry Creek Improvement District No. 4 should be pushed as rapidly as possible.

3. All wooden bridges on the creek should be removed as soon as is practicable, and replaced by bridges giving the freest and largest possible waterway.

4. The proper grades of Cherry Creek as now established should be recognized, and the channel should be brought to that grade from Downing Street to the mouth of the creek at once, and as soon as practicable from Downing Street up the creek to the city limits.

5. The channel should be made clean and kept clean; anyone responsible for placing obstructions in the creek being severely punished.

6. Logan Street bridge should be replaced by a new bridge at once, and Eleventh Street and Thirteenth Street bridges should be replaced as soon as practicable.

7. The creek should be walled as soon as possible from Downing Street up to the city limits, and the channel excavated to grade.

8. The city should acquire title to the channel of South Platte River at once, and exercise police supervision over this channel as well as over the Cherry Creek channel.

9. The pile bridges across the South Platte River, particularly those near the Twentieth Street viaduct, should be replaced by modern steel-truss bridges, without delay.

10. The city should issue bonds to the amount of $1,000,000, this amount to be used in the construction of a reservoir in accordance with the preliminary plans outlined in this report.

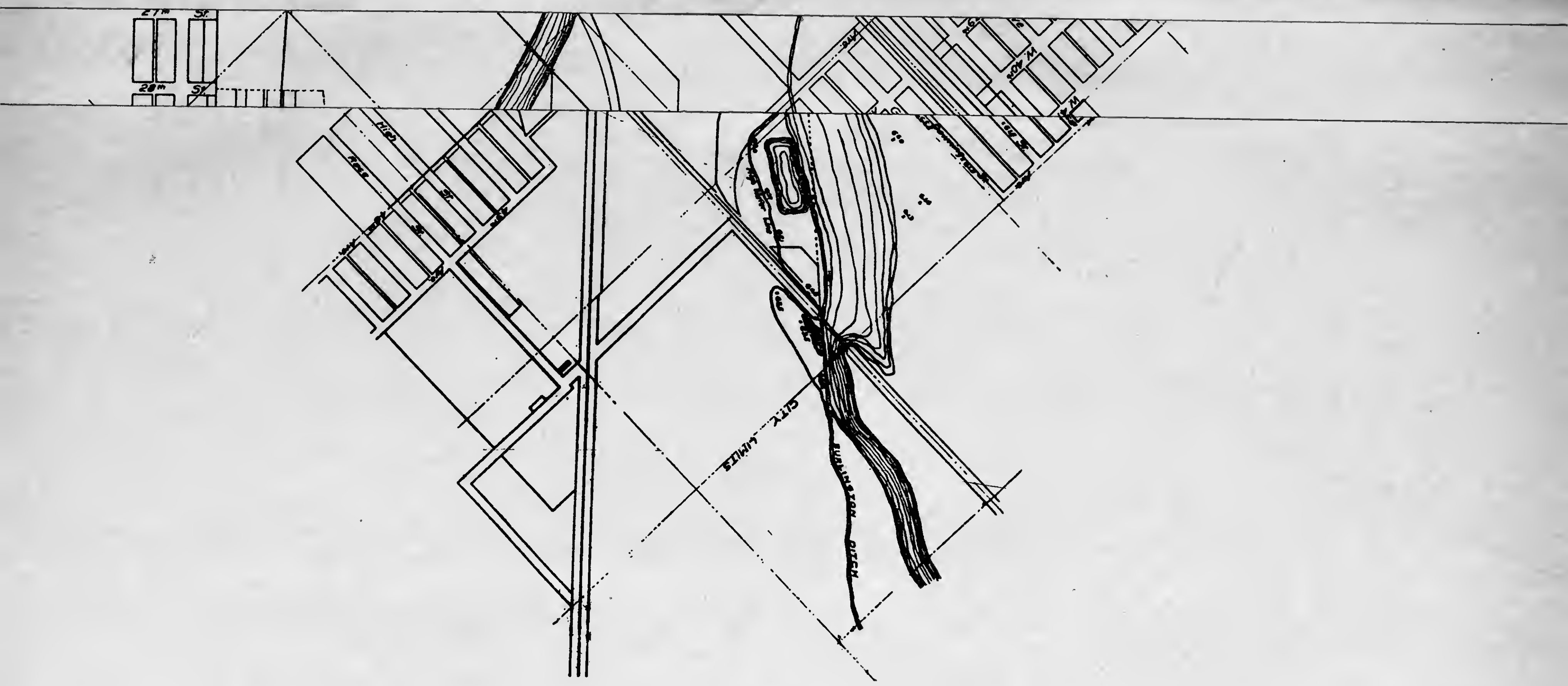
11. A competent board of hydraulic engineers should have charge of the preparation of the detail plans and specifications and the construction of the proposed dam, and nothing should be done in this connection that did not meet with the approval of this board.

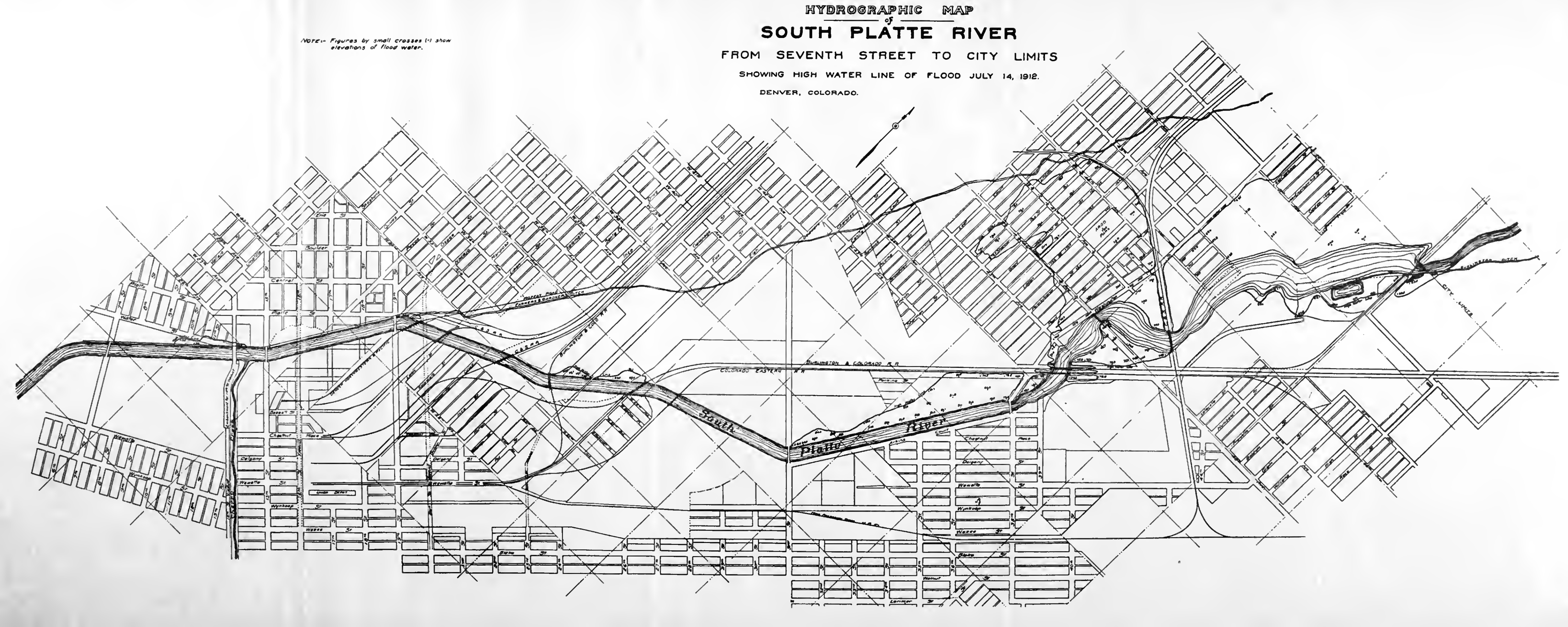
12. A thorough study should be made of the South Platte River also, with a view to the regulation of floods on this stream and its tributaries.

Respectfully submitted,

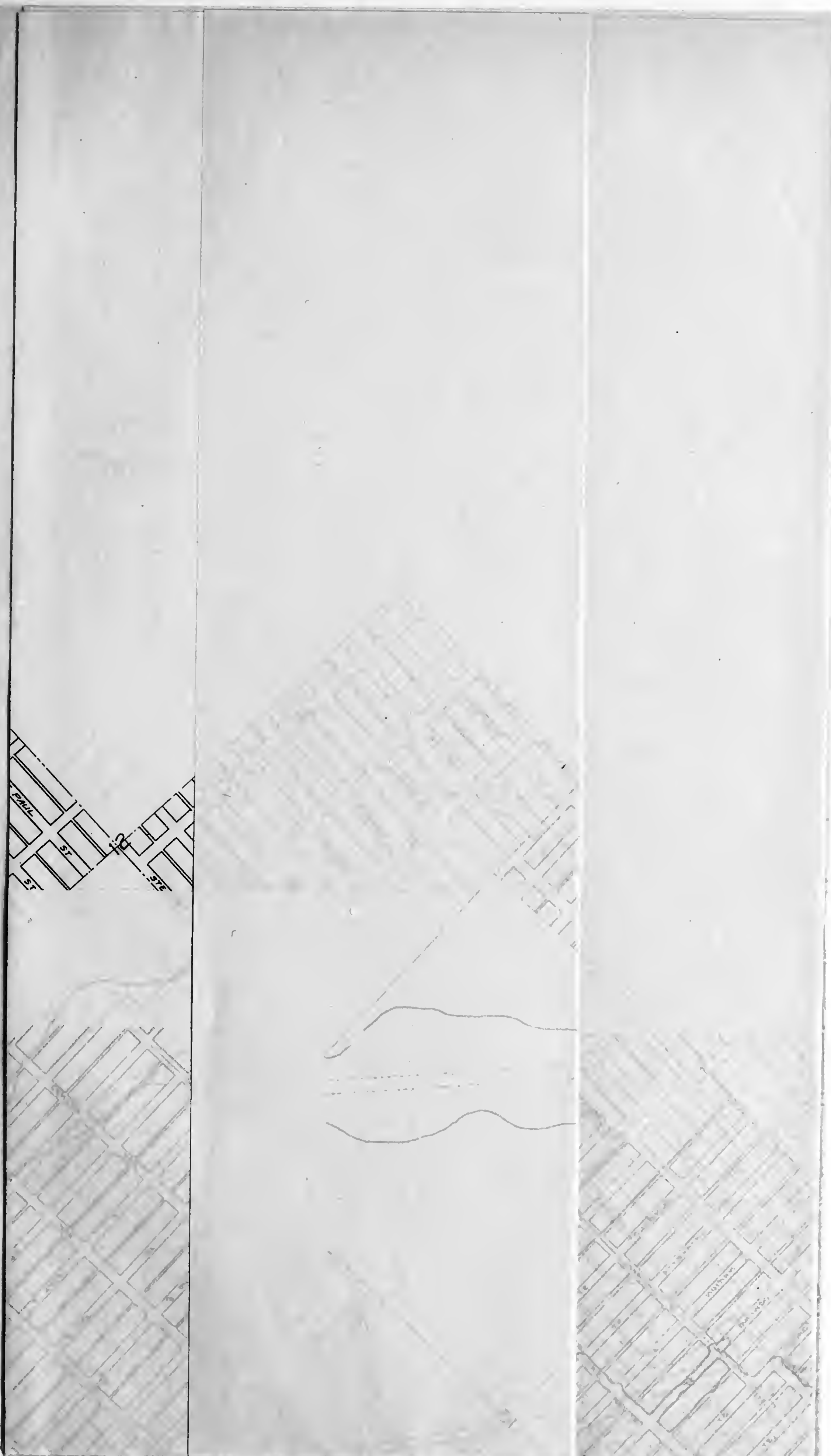
A. LINCOLN FELLOWS,
J. B. HUNTER,
C. A. TREASE,
Cherry Creek Flood Commission.

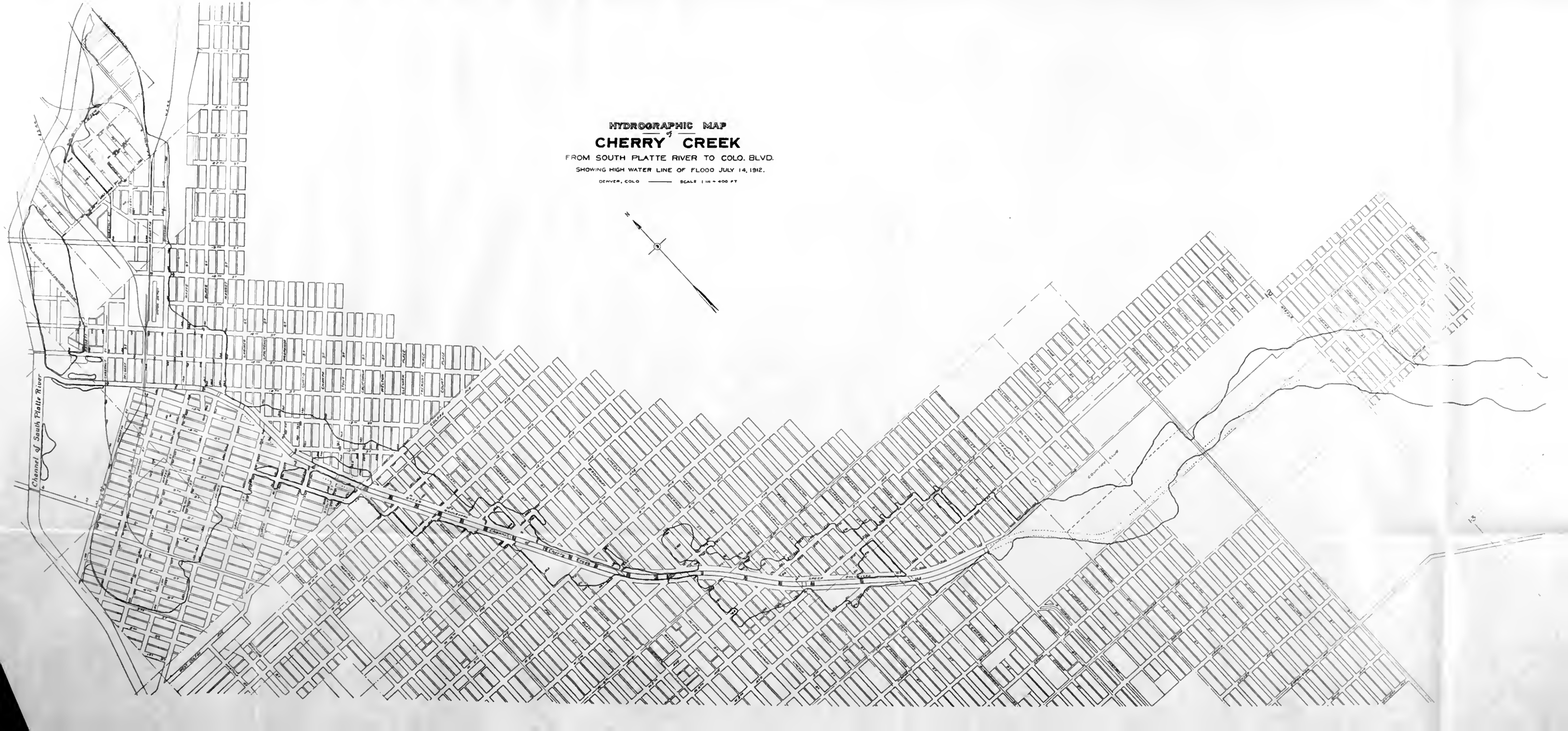
APPENDICES


27th St.
28th St.
High
Rose
W 40th
CITY LIMITS
BURLINGTON DITCH
High Water Line



HYDROGRAPHIC MAP
of
SOUTH PLATTE RIVER
FROM SEVENTH STREET TO CITY LIMITS
SHOWING HIGH WATER LINE OF FLOOD JULY 14, 1912.
DENVER, COLORADO.
NOTE:- Figures by small crosses (+) show elevations of flood water.
South Platte River
COLORADO EASTERN R.R.
BURLINGTON & COLORADO R.R.
CITY LIMITS
UNION DEPOT
Boulder St.
Central St.
Platte St.
Chestnut Place
Delgany St.
Wewatta St.
Wynkoop St.
Wazee St.
Blake St.
Walnut St.
Larimer St.




HYDROGRAPHIC MAP
of
CHERRY CREEK
FROM SOUTH PLATTE RIVER TO COLO. BLVD.
SHOWING HIGH WATER LINE OF FLOOD JULY 14, 1912.
DENVER, COLO
SCALE 1 IN = 400 FT
Channel of South Platte River
COUNTRY CLUB


Channel of South Platte River

APPENDICES

INVESTIGATIONS AND PRELIMINARY REPORTS OF THE CHERRY CREEK FLOOD COMMISSION

Immediately after its creation, the Cherry Creek Flood Commission commenced investigations of the conditions on both Cherry Creek and the South Platte River. Parties were placed in the field, and surveys were made along both streams, special attention being given to the possibilities of diversion and storage on Cherry Creek. A considerable amount of drilling for foundations was done along Cherry Creek, in connection with both the proposed dam sites and proposed bridge abutments and piers. Surveys were made of a number of different diversion lines and of two reservoir sites on Cherry Creek. Topographical surveys were also made along portions of Cherry Creek valley where such surveys seemed specially desirable. A study was made of the area submerged in the flood of July 14, 1912, and maps have been made showing the submerged lands along both Cherry Creek and the South Platte. Surveys were made of the proposed change in the line of the Farmers' and Gardeners' Canal. Information was frequently called for by the Board of Public Works, and preliminary reports, sometimes verbal and sometimes written, were made in response to such inquiries. Among the written reports special mention is made of the following:

The Commission was first requested to report as quickly as possible an approximate estimate of cost of replacing walls that had been destroyed, and of repairing damages along Cherry Creek, between the east line of Acoma and the west line of Downing Streets. Under date of July 26, 1912, a report was made to the Board of Public Works, as follows:

Denver, Colo., July 26, 1912.

The Honorable Board of Public Works,
City and County of Denver,
Building.

Gentlemen: At your request, we herewith submit an approximate estimate of cost of replacing walls and repairing damages along Cherry Creek, caused by the flood of July 14, 1912, between the east line of Acoma and the west line of Downing Streets:

1,587 linear feet of wall to be replaced, at $9.00 per foot	$14,283.00
451 linear feet of auxiliary wall, at $3.00 per foot	1,353.00
266 linear feet of hand-railing, at $2.50 per foot	665.00
450 linear feet of concrete curb and gutter, at $0.60 per foot	270.00
935 linear feet of 5-foot cement sidewalk, at $0.50 per foot	467.50
15,566 cubic yards of earth fill, at $0.20 per yard	3,113.20
820 linear feet of 4-inch water pipe, at $0.40 per foot	328.00
8 lamp posts, at $25.00 each	200.00
	$20,679.70

Respectfully submitted,

(Signed) A. LINCOLN FELLOWS,
J. B. HUNTER,
C. A. TREASE,
Commission on Cherry Creek.

As soon as practicable, work was commenced on Cherry Creek. It was necessary first, of course, for funds to be provided. It was made possible for construction work to be undertaken by action of the Council August 28, and the first work undertaken with the approval of the Commission was the repairing of the Thirteenth Street sewer, which had been washed out by the flood. This work was followed, as soon as contracts could be let, by repairs to the walls and other structures which had been damaged.

Under date of August 19, 1912, a report was submitted to the Board of Public Works, setting forth certain facts and conditions regarding the channel of the South Platte River within the city limits, and certain recommendations were made, which are contained in the following report:

August 19, 1912.

The Honorable Board of Public Works,
City and County of Denver,
Office.

Gentlemen: Pursuant to your request, we herewith submit report of facts and conditions of the channel of the South Platte River within the city limits, together with certain recommendations concerning this stream.

Ordinance No. 25 of the series of 1894 establishes a channel for the Platte River 200 feet wide, from Nineteenth Street to Thirty-eighth Street. Ordinance No. 13 of 1895 establishes the channel 200 feet wide from a point near West Twenty-first Avenue to Nineteenth Street. Ordinance No. 117 of the series of 1910 establishes the channel 150 feet wide from Warren Avenue to a point near West Twenty-first Avenue.

From Yale Avenue, the south city limits, to Warren Avenue, a distance of about 4,000 feet, and from Thirty-eighth Street to the north city limits, a distance of about 7,000 feet, the channel of the river has never been established. While the ordinances above mentioned all give the city the right to acquire title to the

land included in the described channel, in no case has this been done, and the city has not title to any of the land, so far as we have been able to ascertain. We think the city should have title to and control over all the land within the established channel of the river from the south to the north city limits, and to that end would recommend that the proper city officials proceed at once to acquire title to the land, as provided for in the above-named ordinances, and that your Board have the necessary surveys made and ordinances prepared to officially establish the channel for the river from Thirty-eighth Street to the north city limits, and from Warren Avenue to the south city limits.

We have made an inspection of the Platte River for its entire length through the city, a distance of about ten and one-fourth miles, and find the condition of the channel to be very bad, owing to the many obstructions that have been placed in the stream by different railroad companies and others; also by the number of bars and islands that have formed, most of which are covered with brush and quite large trees; in many places the stream has only from sixty to eighty feet of waterway. Between Nineteenth Street and a point where Twenty-eighth Street, if extended, would cross the river, there are six railroad bridges, all constructed on pile bents that are not more than twenty feet apart; also the approach to the Twenty-third Street viaduct, which is a pile structure, built by N. P. Hill in 1887. This approach should be replaced with a steel or concrete structure, and the railroad companies should, if possible, be compelled to remove all pile bridges and construct new bridges, where necessary, of such design as will obstruct the stream as little as possible.

The Colorado and Southern has a steel-plate girder bridge across the channel near Jason Street. This is a new bridge and a good one, but it is too low and should be raised about four feet. The water of the flood of July 14 was one foot up on the girder of this bridge. There is a twenty-four-inch cast-iron pipe across the channel at this point. This pipe was placed here to carry the sewerage from North Denver across the river to the Delgany Street sewer, but has been abandoned since the West and South Side Sanitary Sewer has been constructed. This pipe should be removed by the city, as it only serves to form a dam in the stream. The diverting dam across the river just above Nineteenth Street has partly washed out. What remains should be taken out, as it is intended to supply the Farmers' and Gardeners' Ditch for which this dam was constructed, by taking the water through a conduit along the north side of the river from the present head gate, west to the tramway power-house.

The Colorado and Southern has a pile bridge across the channel just above Seventh Street, and one near West Fourth Avenue.

The Inter-Mountain has a double-track pile bridge at West Fourteenth Avenue. These bridges should be removed, and new ones built that will allow for a free passage of the water.

The city has ten pile bridges across the channel at the following streets:

At Forty-sixth Avenue, Seventh Street, West Thirteenth Avenue, West Eleventh, West Eighth, Vallejo Street, West Third Avenue, West Bayaud, West Mississippi, and West Florida Avenue, with the exception of the bridge at Florida.

These are all old bridges, the pile bents being only twenty feet. It is our opinion that the city should replace all these bridges, as soon as possible, with new steel or concrete structures. The facts are that the Platte River, extending, as it does, for a distance of more than ten miles through the city, is in a dangerous condition, and we most earnestly recommend that your Honorable Board take the necessary steps to eliminate this condition as far as possible, by first acquiring title to the channel of the river by the different ordinances referred to, and, second, by having the channel cleared of the obstructions which we have mentioned.

If this were done, and the banks raised and riprapped where they are too low, we are of the opinion that the channel, as at present defined, would safely carry the waters of any flood that might occur. Otherwise, with this stream in its present condition, if we should have a flood in the Platte River as large in proportion as the one in Cherry Creek on July 14, it would cause untold damage to property and endanger many lives.

Respectfully yours,

(Signed) A. LINCOLN FELLOWS,
J. B. HUNTER,
C. A. TREASE,
Cherry Creek Commission.

Under date of August 22, 1912, a report concerning Cherry Creek, similar to that made concerning the South Platte under date of August 19, was made to the Board of Public Works. This report is as follows:

August 22, 1912.

The Honorable Board of Public Works,
City and County of Denver,
Building.

Gentlemen: In accordance with your request for a report on the conditions of the channel of Cherry Creek and the different bridges across the channel, with our recommendations as to what should be done for the betterment of the present conditions, we respectfully submit the following:

Ordinance No. 86 of the series of 1903 adopts a map, which is among the records of the Engineering Department, showing a channel 100 feet wide from the Platte River to Colfax Avenue.

Ordinance No. 37 of the series of 1894 establishes the channel 116 feet wide from the center of Colfax Avenue to the center of Broadway. This includes space necessary for the construction of levees or walls.

Ordinance No. 72 of the series of 1906 establishes the channel ninety-six feet wide from the center line of Broadway to the west line of Downing Street.

Ordinance No. 120 of the series of 1902 defines the bed of Cherry Creek 130 feet wide from the west line of Downing Street to the easterly city limits. This includes the necessary space for the construction of walls, embankments, and appurtenances.

The city has the title to the present channel of Cherry Creek from Chestnut Street to Downing Street, except four parcels of land numbered 103, 106, 107, and 109, as shown on map referred to in the report of Cherry Creek Commission, appointed by authority of Ordinance No. 7 of 1903. This commission was composed of Samuel S. Landon, John M. Borkey, and A. B. Seaman. This commission made a very valuable report on the titles to the lands lying within the bed of Cherry Creek as per the Ebert survey. This report is on file in the Engineer's Department.

From Chestnut Street to the Platte River the city has no title to the channel of the creek as now defined. We would recommend that the proper city officials acquire title to the lands above mentioned, as soon as possible.

From Downing Street to the easterly city limits the city has no title whatever to any of the bed of the creek. While Ordinance No. 120 of 1902 defines a channel 130 feet wide, no steps have been taken by the city to acquire title to the land, and, as we understand that the owners of the lands between Downing and York Streets object to having the channel placed where this ordinance specifies, and inasmuch as 130 feet is a greater width than we deem necessary for the channel of the creek between these two points, we recommend that a new survey be made, and a new ordinance prepared, defining the channel of the creek a proper width, from Downing Street to the easterly city limits. This new channel may possibly more nearly conform to the wishes of the property-owners who object to the lines as now defined by Ordinance No. 120 of the series of 1902. The city should then acquire title to that part of the channel under the new ordinance.

We would recommend that the channel of the creek from Blake Street to the Platte River, which is now in many places almost entirely filled with earth and rubbish, be cleaned out for its entire width of 100 feet, and that suitable walls be constructed, leaving the channel between these two points 100 feet wide, as now established.

There are at the present time twenty-eight bridges across the creek within the city limits. Of this number eight are railroad bridges, located at the following points: one C. & S. pile bridge just below Chestnut Street, one double-track C. & S. pile bridge

at Chestnut Street, one B. & M. steel-truss bridge at Chestnut Street, one C. & S. steel-truss bridge at alley between Chestnut and Delgany Streets, one C. & S. pile bridge at Delgany Street, one C. & S. steel-truss double-track bridge at Wewatta Street, one D. & R. G. steel-truss bridge at Wynkoop Street, and one D. & R. G. steel-truss double-track bridge at Wewatta Street.

The pile bridges should be removed, and steel bridges constructed of such design as will give at least nine feet clear waterway. This would allow for a flow of about 12,000 cubic feet per second.

The steel-truss bridges should be raised sufficiently to give an equal space for waterway. This can be done by the different railroad companies, and not require the raising of the Fourteenth Street viaduct at the points where the railroad tracks cross under it. If the railroad bridges are raised higher than this nine-foot clearance for waterway, the viaduct must be raised correspondingly.

The city has twenty bridges across the creek, four of which are pile bridges, located at the following points: Delganty Street, York Street, Steele Street, and Colorado Boulevard. These should all be removed and replaced with steel or concrete structures.

The steel-plate girder bridge at Wazee Street, in its present position, will have ten feet waterway. The steel-plate girder bridge at Blake Street, together with the Fourteenth Street viaduct approach, as at present constructed, will have a clear waterway of nine feet.

While the greatest damage to private property in the recent flood in the creek was caused by the choking of the stream at this point, it was, in our opinion, almost, if not entirely, due to the condition of the channel both above and below this point at the time of the flood.

Your Honorable Board has already taken steps to have the present steel-truss bridge at Market Street removed, and a new bridge constructed at this crossing.

The steel-truss bridge at Larimer Street will have a clear waterway of ten feet.

The sanitary sewer crossing the creek at Lawrence Street, which was washed out—the plans have been prepared for replacing this sewer by a syphon.

The steel-truss bridge at Curtis Street is in a very bad condition. On May 3, 1910, Messrs. Crocker and Ketchum reported this bridge to be in a dangerous condition, and recommended that it be closed to traffic. This bridge should be taken down at once, and a new bridge constructed in its place.

The steel-truss bridge at Champa Street has ten feet clearance; the one at Stout Street, twelve feet, and the one at Colfax Avenue, fourteen feet. There is a water-pipe across the creek at Stout Street which is above the present bed; it should be lowered.

The gas and water mains at Colfax Avenue should both be lowered.

The steel-truss bridge at West Thirteenth Avenue has but eight feet clearance. This bridge can be raised, but we would recommend that it be taken down, and a new one constructed.

The bridge at West Eleventh Avenue has a clearance of nine feet. The creek bed is considerably below the west abutment. This bridge should also be replaced with a new one.

The reinforced concrete bridge at Bannock Street has at its highest point a clearance of twelve feet; all of the flood of July 14 passed under this bridge.

The steel girder at Broadway has a clear waterway of nine feet.

The bridge at Logan Street is a steel truss, and has at the present time but five feet of unobstructed waterway. It is entirely too low. It is constructed at right angle with the creek, and in its present position a sharp angle is formed in the roadway at both the north and south ends of the bridge, making it dangerous to travel, which is very large over this bridge. We would therefore recommend that the present bridge be removed, and a new one constructed at this point, that will more nearly conform to the street on the north and south sides of the creek, and eliminate danger to travel.

The bridge at Clarkson Street has nine feet clearance. It is in a very poor condition, and should be replaced with a new bridge.

You already have under consideration the building of a new bridge at Downing Street, which should be constructed as soon as possible.

As stated before, the city has no title to any part of the channel of Cherry Creek above Downing Street. A great many different propositions have been suggested as to what should be done with the Cherry Creek channel to prevent damage to the city from flood waters. At the present time we have not proceeded far enough with our investigations and surveys to report which is, in our judgment, the better, and this report is intended only to give your Honorable Board a statement of the present condition of the channel of Cherry Creek, and the different bridges that are now in place across the creek, and the recommendations made are based on the supposition that the present channel and walls are to remain substantially as at present constructed. Should the widening of the channel to a width of 110 feet, and the raising of the walls and bridges, be adopted, all the conditions would be changed. But, regardless of what plan may finally be adopted, we would recommend that the present channel be cleared of all obstructions, such as old piling, pile bridges, dams, trees, dirt, and rubbish, so that the flow of the water may be unob-

structed, as far as possible, until such time as a definite plan may be adopted and carried out.

Very respectfully,

(Signed) A. LINCOLN FELLOWS,
J. B. HUNTER,
C. A. TREASE,
Cherry Creek Commission.

This report was supplemented at a later date by a list of bridges crossing Cherry Creek within the city limits, as follows:

BRIDGES ON CHERRY CREEK FROM COLORADO BOULEVARD TO THE SOUTH PLATTE RIVER, PREVIOUS TO THE FLOOD OF JULY 14, 1912

		Length in Feet
1.	Colorado Boulevard, wooden bridge resting on piles.	
2.	Steele Street, wooden bridge resting on piles.	
3.	York Street, wooden bridge resting on piles, together with City Ditch Flume on upper side of the bridge.	
	(All of these pile bridges were destroyed almost completely.)	
4.	Downing Street, steel-truss bridge	104.50
5.	Clarkson Street, steel-truss bridge	131.00
6.	Logan Street, steel-truss bridge	110.00
7.	Broadway, steel-plate girder bridge	116.00
8.	Bannock Street, reinforced concrete bridge	142.50
9.	West Eleventh Avenue, steel-truss bridge	104.50
10.	West Thirteenth Avenue, steel-truss bridge	125.75
11.	West Colfax Avenue, steel-truss bridge	129.00
12.	Stout Street, steel-truss bridge	106.00
13.	Champa Street, steel-truss bridge	126.00
14.	Curtis Street, steel-truss bridge	125.50
15.	Lawrence Street, steel-girder bridge, two-span	156.00
16.	Larimer Street, steel-truss bridge	106.50
17.	Market Street, steel-truss bridge	119.00
18.	Blake Street, plate-girder bridge	103.00
19.	Wazee Street, steel-plate girder bridge	114.00
20.	Wewatta Street, steel-truss bridge, D. & R. G. R. R.	104.50
21.	Wynkoop Street, steel-truss bridge, D. & R. G. R. R.	105.00
22.	Wynkoop Street, steel-truss bridge, C. & S. R. R.	105.00
23.	Delgany Street, pile bridge	96.00
24.	Delgany Street, pile bridge, C. & S. R. R.	96.00
25.	Alley between Delgany and Chestnut Streets, steel-truss bridge, C. & S. R. R.	111.50
26.	Wewatta Street, steel-truss bridge, C. B. & Q. R. R.	119.00
27.	Wewatta Street, pile bridge, C. & S. R. R.	100.00
28.	Wewatta Street, pile bridge, D. & R. G. R. R.	100.00

Under date of August 6, 1912, and also under date of September 7, 1912, the Commission reported upon the necessary work in repairing damages above the Downing Street bridge, as follows:

September 7, 1912.

The Honorable Board of Public Works,
City and County of Denver,
Building.

Gentlemen: Pursuant to your request for a statement of the work necessary in repairing damages along Cherry Creek above the Downing Street bridge on the Country Club grounds, we submitted, on the 6th day of August, the following report, which will not be very materially altered:

Denver, Colorado, August 6, 1912.

The Honorable Board of Public Works,
City and County of Denver,
Building.

Gentlemen: In pursuance of your request for a statement of the work necessary in repairing damages along Cherry Creek above the Downing Street bridge and adjacent to the Country Club grounds, we submit the following:

We find that on the north side of the creek, from a point about 350 feet east of the present Downing Street bridge, the walls should be extended along the official north line for a distance of about 900 feet. We are of the opinion also that about 400 feet of wall should be constructed on the south side of the stream, extending in the southeasterly direction from the south end of the Downing Street bridge.

About 385 feet of the storm sewer, one manhole, and one catch-basin are washed out and destroyed. If arrangements can be made with the Country Club, the line of this sewer may be so changed, discharging at a higher point on the stream, that only 180 feet of new outlet will be required, costing proportionately less than the longer line.

There will also be required about 7,000 cubic yards of earth for refilling First Avenue, 266 linear feet of concrete curb and gutter to be replaced, and possibly 125 feet of five-foot sidewalk to be replaced. Aside from the 1,300 feet of new wall recommended to be built in the Country Club grounds, all of the work mentioned above is repair work, the cost of which must be borne by the city.

We recommend that the Country Club, and others interested in having this wall built, be consulted, and that an agreement be made as to what portion of the cost shall be borne by the city.

We also recommend that all of the work, including the construction of the wall, be done at one time, so as to insure the co-ordination of the various parts of the work.

Our estimate, including all costs of excavation and backfilling for above walls and sewer is as follows:

North wall, 900 linear feet, at $9.00		$8,100.00
South wall, 400 linear feet, at $9.00		3,600.00
Storm sewer, 385 feet, at $6.00	$2,310.00	
One manhole	35.00	
One catch-basin	35.00	
		2,380.00
Refilling First Avenue, 7,000 cubic yards, at 20 cents	$1,400.00	
Curb and gutter, 266 feet, at 55 cents	146.30	
Sidewalk, 125 feet, at 50 cents	62.50	
		1,608.80
Total		$15,688.80
Assuming that the sewer line can be shortened 205 feet, as suggested above, the above estimate would be reduced.		1,230.00
This would reduce the amount of the estimate to		$14,458.80
Add for supervision		541.20
Gives a total of		$15,000.00

This we believe to be a conservative estimate for the work described, and see no reason why it cannot be done.

In addition to this work, however, we believe that the Country Club ought to agree to extend the north wall for a considerable distance along the north side of the official channel by means of a pile, or even more permanent structure, at their own expense. This need not enter into our calculations at this time, but we are of the opinion that the desirability of this extension should be strongly impressed upon the Country Club.

Very respectfully,

(Signed) A. LINCOLN FELLOWS,
J. B. HUNTER,
C. A. TREASE,
Cherry Creek Commission.

The revised estimate will be as follows:

North wall, 820 linear feet, at $9.00	$7,380.00	
South wall, 400 linear feet, at $9.00	3,600.00	
With wing wall, 166 linear feet of piling, at $3.50	581.00	
		$11,561.00
Storm sewer, 385 feet, 54-inch, brick, at $6.00 per foot	$2,310.00	
One manhole	35.00	
One catch-basin	35.00	
		2,380.00
Refilling First Avenue, 7,000 cubic yards, at 20 cents	$1,400.00	
266 feet concrete curb and gutter, at 55 cents	146.30	
125 feet sidewalk, at 50 cents	62.50	
		1,608.80
For supervision		550.00
Total		$16,099.80

If concrete wing wall is constructed instead of piling, the estimate will be as follows:

North wall, 820 linear feet, at $9.00	$7,380.00	
South wall, 400 linear feet, at $9.00	3,600.00	
Wing wall, 166 linear feet, with concrete, at $9.00	1,494.00	
		$12,474.00
Storm sewer, 285 feet, 54-inch, brick, at $6.00 per foot	$2,310.00	
One manhole	35.00	
One catch-basin	35.00	
		2,380.00
Refilling First Avenue, 7,000 cubic yards, at 20 cents	$1,400.00	
266 linear feet concrete curb and gutter, at 55 cents	146.30	
125 feet sidewalk, at 50 cents	62.50	
		1,608.80
For supervision		550.00
Total		$17,012.80

This estimate does not contemplate the complete filling of all the area between First Avenue and the proposed wall, but only so much of same as will protect the wall and the refilling First Avenue to grade its full width.

We also wish to report the completion of the topographical survey of the Country Club grounds, which is included in this

report and consists of two sheets, eighteen by twenty-four inches each.

Respectfully submitted,

(Signed) A. LINCOLN FELLOWS,
J. B. HUNTER,
C. A. TREASE,
Cherry Creek Commission.

Checked level lines have also been run along Cherry Creek, and the Commission has established grades and made recommendations as to the lowering of water mains and gas pipes. Instructions have been given to the Denver Union Water Company and to the Denver Gas and Electric Company in accordance with these recommendations.

Recommendations have also been made regarding the acquisition of rights of way both from Blake Street down to the river and from Downing Street up the creek to the city limits. The removal of all pile bridges has been strongly recommended, and arrangements have been made for the putting-in of steel-truss bridges in place of all the pile bridges on Cherry Creek. The Commission has recommended that the West Thirteenth and West Eleventh Street bridges be replaced as early as practicable, and it is strongly recommended that the Logan Street bridge be replaced as soon as possible, on account of the inadequacy of the waterway at that point. It has, furthermore, urged the removal of all obstructions in the stream within the city limits, the construction of cut-off walls where needed, and the creation of Cherry Creek Improvement District No. 4, for the purpose of walling the stream from Blake Street to its mouth.

These recommendations have generally been followed, or the construction recommended is contemplated in the near future. On South Platte River the Commission has recommended the removal of the dam at the head of the Farmers' and Gardeners' Canal and the construction of a concrete conduit about 2,000 feet in length, with a view to taking water from the South Platte River at a point just above the mouth of Cherry Creek. This work has been done.

EXPENSES AND SALARIES OF CHERRY CREEK FLOOD COMMISSION FROM JULY 17, 1912, TO NOVEMBER 30, 1912

Appraisal of lands and reservoir site	$200.00
Drilling	584.50
Expenses of miscellaneous surveys	1,476.99
Salaries of the Commission	3,437.62
Total	$5,699.11

WORK DONE AND CONTEMPLATED

A considerable amount of work has been done in connection with repairing of the Cherry Creek channel, in the main in consequence of damages caused by the Cherry Creek flood of July 14, 1912. The principal work done up to the present time, and works still remaining to be done, are as follows:

Street Repairs and Miscellaneous Work.—Immediately after the flood a very large amount of work had to be done under the direction of the Commissioner of Highways, in putting in good condition the streets of the city, and particularly those of the lower portions of the city. A large amount of work was also done in pumping water from basins and low-lying tracts, for the benefit of the poorer residents of those sections. This department did a large amount of work in cleaning out the drift piled against bridges and those portions of the Cherry Creek channel most needing excavation and cleaning.

Bridges.—About 134 feet of the north end of the approach to the Colorado Boulevard pile bridge was washed away, and about forty feet of the north end of the bridge was badly wrecked. This approach and bridge have been repaired, at a cost of $793.90, one-half of which was paid by Arapahoe County. It is proposed by the Board of Public Works to replace this bridge by the steel-truss bridge removed from Downing Street, at a cost estimated at $5,000.

The Steele Street pile bridge was completely destroyed and washed away, only a portion of the concrete main wall on the north side of the creek and part of the approach being left to indicate the location of the bridge. No attempt has as yet been made to replace this bridge.

About 120 feet of the York Street pile bridge was washed away, together with an equal amount of the City Ditch Flume, which adjoins the bridge. Both of these were temporarily repaired, at a cost of about $882.55. It is intended by the Board of Public Works, however, to replace this bridge by the steel-truss bridge which has been removed from Larimer Street. The estimated cost is $7,600.

About half of the south abutment of the Downing Street bridge was wrecked, and the south approach was washed away, leaving this bridge temporarily out of commission. It has since been replaced by a concrete bridge of the mushroom type of reinforcement. This bridge has two spans, with columns in the center

of the stream. The cost of the new bridge and the removal of the old bridge amounts to $18,106.50.

The Logan Street bridge was damaged to some extent through injury to the handrail and sidewalk and a portion of the roadway. The damaged portions of the bridge have been repaired at a cost of a few dollars.

A part of the handrail and sidewalk of the up-stream side of the West Eleventh Avenue steel bridge was damaged and has been repaired at a cost of a few dollars only.

A part of the handrail and sidewalk on the up-stream side of the Curtis Street bridge was damaged and was temporarily repaired. The bridge was also removed, and a concrete bridge of the mushroom type of reinforcement, having two spans of forty feet each, has been constructed at a cost—

For the new bridge	$12,588.00
Removal of old bridge	387.25
	$12,975.25

The Larimer Street steel bridge was not injured by the flood, but it has since been replaced by a reinforced concrete bridge of the mushroom type of reinforcement, having two spans of forty feet each, with columns connected by a web in the center of the channel, at a cost of—

New bridge	$17,485.50
Removal of old bridge	1,000.00
	$18,485.50

The Market Street steel bridge was considerably damaged, a portion of the handrail and sidewalk of both sides of the bridge being injured, and also a portion of the roadway. The roadway and down-stream side of the sidewalk and handrail were repaired, at a small cost. The bridge was also removed, and a reinforced concrete bridge of the mushroom type of reinforcement erected in its place, at a cost of—

New bridge	$18,827.00
Removal of old bridge	500.00
	$19,327.00

The old bridge has been stored for future use.

A part of the handrail and sidewalk on the up-stream side of the Blake Street and Fourteenth Street approaches to the Fourteenth Street viaduct was damaged and has been repaired at a small cost.

The wooden pile bridge across the channel at Delgany Street acted as a barrier, and considerable drift lodged against this

bridge and the adjacent railroad bridge. It is proposed to replace this bridge with the old Curtis Street steel bridge, at a cost of approximately $1,500.

The pile bridge belonging to the Colorado & Southern Railway is being replaced this year by a modern steel-truss bridge spanning the entire channel, with a clearance of at least nine feet.

The pile bridge belonging to the Denver & Rio Grande Railway has been replaced by a modern steel bridge spanning the entire channel, having a clearance of nine feet from the present bed of the stream.

Sixteen hundred feet of retaining wall destroyed by the flood has been repaired, at a cost of $32,968.10.

Eleven hundred and ninety linear feet of sidewalk, five feet in width, on Speer Boulevard near Broadway and Downing Street and on First Avenue between Marion and Lafayette Streets, has been repaired, at a cost of $994.92; and 1,865 square feet of sidewalk has been relaid, at 2 cents a foot, or $39.90.

Four hundred and fifty linear feet of combined concrete curb and gutter was damaged, and 402 linear feet of combined concrete curb and gutter is to be constructed on account of new bridge construction.

852 linear feet, at 60 cents	$511.20
596.5 linear feet of curb to be reset, at 20 cents	119.30
Total	$630.50

Seven electric-light standards were wrecked, and have been reset at a cost of $40 each; total, $280.

Eight hundred and twenty-two linear feet of cast-iron water pipe was wrecked, and is replaced at a cost of $697.

Three hundred and eighty-five linear feet of fifty-six-inch storm sewer was washed out on First Avenue, from Lafayette to Marion Street, and has been reconstructed—

At a cost of	$4,574.83
Extension of storm sewer, Seventh Avenue and Broadway	177.96
Total	$4,752.79

Ninety linear feet of vitrified pipe sewer across Cherry Creek at Lawrence Street has been destroyed, and has been reconstructed as a syphon in duplicate, at a cost of $2,757.93; 435 linear feet of ten-inch vitrified pipe sewer on First Avenue from Lafayette Street to alley between Lafayette and Marion Streets has been reconstructed, at a cost of $70; total, $2,827.93.

A portion of the paved roadway on Speer Boulevard at Lincoln Street, 450 feet in length, was washed out and has been regraded, but not yet repaved.

First Avenue from Lafayette to Marion Street was washed out and has been partially regraded, the cost being charged to repairs of storm sewers.

A portion of the Farmers' and Gardeners' Ditch dam across the South Platte River near Nineteenth Street was destroyed by the flood. The remaining portions of the dam have been removed, and a concrete conduit, 3.6 feet in width and 2.2 feet in depth, has been constructed, extending up the river about 2,000 feet to the tramway power-house south of Fifteenth Street, at a cost of $11,241.14.

The center pier of the Fifteenth Street bridge was strengthened by the construction of a concrete base.

Four hundred and fifty feet of the channel of Cherry Creek just below Broadway bridge is being paved, at an estimated cost of $13,778.95.

The weir walls or concrete dams along Cherry Creek and West Colfax Avenue to Downing Street have been removed, at a cost of $2,160.

A number of curtain walls have been constructed across the creek at such points as were deemed most in need of them.

The total cost of the work done to date is not yet estimated.

Cherry Creek Improvement District No. 4, contemplating the construction of walls along Cherry Creek from Blake Street to the mouth of the creek, together with the construction of curtain walls across the creek and the excavation of the creek-bed to grade, has been created, and a contract for the work will be let in the near future, at an estimated cost of $144,478.51.

Small repairs to bridges, sidewalks, paving, etc., still remain to be done, the estimated cost amounting to approximately $1,000.

RECAPITULATION

Repairs to Colorado Boulevard bridge	$ 793.90	
Repairs to York Street bridge	882.55	
Repairs to sidewalk	1,034.82	
Repairs to curb and gutter	630.50	
Repairs to electric-light standards	280.00	
Repairs to water pipe	697.00	
Repairs to storm sewer	4,752.79	
Repairs to Thirteenth Street sanitary sewer	2,827.93	
Removing weir walls or dams	2,160.00	
Repairs to bridges, estimated	1,000.00	
		$ 15,059.49
Proposed reconstruction of old bridges—		
Colorado Boulevard	$ 5,000.00	
York Street	7,600.00	
Delgany Street	1,500.00	
		14,100.00
Reconstruction of walls	$32,968.10	
Farmers' and Gardeners' Ditch conduit	11,241.14	
Cherry Creek paving	13,778.95	
		57,988.19
Cherry Creek Improvement District No. 4		144,478.51
Construction of concrete bridges—		
Downing Street	$18,106.50	
Curtis Street	12,975.25	
Larimer Street	18,485.50	
Market Street	19,327.00	
		68,894.25
Total		$300,520.44

FLOOD OF MAY 19 AND 20, 1864

The disastrous results of this flood are best described by Professor A. J. Goldrick in the *Commonwealth,* May 24, 1864 (the *Rocky Mountain News,* with which he was connected, having been washed away by this flood). This description is given without change, in Professor Goldrick's own peculiar style.

About the midnight hour of Thursday, the nineteenth instant, when all in town were knotted in the peace of sleep, deaf to all noise and blind to all danger; snoring in calm security, and seeing visions of remoteness radiant with the rainbow hues of past associations, or roseate with the gilded hopes of the fanciful future—while the fullfaced queen of night shed showers of silver from the starry throne down o'er fields of freshness and fertility, garnishing and suffusing sleeping nature with her balmy brightness, fringing the feathery cottonwoods with lustre, enameling the housetops with coats of pearl, bridging the erst placid Platte with beams of radiance, and bathing the arid sands of Cherry Creek with dewy beauty—a frightful phenomenon sounded in the distance, and a shocking calamity presently charged upon us. The few who had not retired to bed, broke from their buildings to see what was coming. Hark! what and where was this? A torrent or a tornado? And where can it be coming from, and whither going? These were the questions soliloquized and spoken, one to the other. Has creation's God forsaken us, and has chaos come again? Our eyes might bewilder and our ears deceive, but our hearts, all trembling, and our sacred souls soon whispered what it was—the thunders of omnipotence warning us "there's danger on the wing," with death himself seeming to prompt our preparation for the terrible alternative of destruction or defence. Presently the great noise of mighty waters, like the roaring of Niagara, or the rumbling of an enraged Etna, burst upon us, distinctly and regularly in its sounding steps as the approach of a tremendous train of locomotives. There was soon a hurrying to and fro in terror, trying to wake up one's relatives and neighbors, while some favored few who were already dressed, darted out of doors, and clamorously called their friends to climb the adjacent bluffs and see with certainty for themselves. Alas and wonderful to behold! it was the water engine of death dragging its destroying train of maddened waves, that defied the eye to number them, which was rushing down upon us, now following its former channel, and now tunneling direct through banks and bottoms a new channel of its own. Alarm flew around and all alike were ignorant of what to think, or say, or do, much less of knowing where to go with safety, or to save others. A thousand terrors thrilled us through. What does this mean? Where has this tremendous flood or freshet, this terrific torrent come from? Has the Platte switched off from its time-worn track and turned its treasure down to deluge us? Have the wild waterspouts from

all the clouds at once conspired to drain their upper cisterns, and thus drench us here in death? Have the firm foundations of the Almighty's earth given way, and the fountains of the great deep burst forth on fallen men, regardless of that rainbow covenant which spanned in splendor yon arc of sky last evening? Is the world coming to an end, or a special wreck of matter impending? These and thoughts like these, troubled the most fearless souls.

ITS PROGRESS OF DESTRUCTION

Now the torrent, swelled and thickened, showed itself in sight, sweeping tremendous trees and dwelling houses before it—a mighty rush of impetuous water, wall-like in its advancing front, as was the old Red Sea when the Israelites walked through it and volcano-like in its floods of foaming, living lava, as it rolled with maddened momentum directly towards the Larimer street bridge and gorged, afterwards rebounding with impetuous rage and striking the large Methodist Church and the adjoining buildings, all of which it wrested from their foundations and engulfed in the yawn of bellowing billows as they broke over the McGaa (Market) street bridge. Like death, leveling all things in its march, the now overwhelming flood upheaved the bridge and the two buildings by it, Messrs. Sharles & Hunts' law offices, in the latter of which C. Bruce Haynes was sleeping, whom, with the velocity of a cataract, it launched asleep and naked on the watery ocean of eternity, to find his final, fatal refuge only in the flood-gate port of death! Poor Haynes! Your summons came, but 'twas short and sudden, after and not before you had "wrapped the drapery" of your humble couch about you, and had lain down to "pleasant dreams." Precipitately and in paroxysms the tempestuous torrent swept along; now twenty feet in the channel's bed, and bridging bank to bank with billows high as hills piled upon hills—broken with buildings, tables, bedsteads, baggage, boulders, mammoth trees, leviathan logs, and human beings buffeting with the billow crests and beckoning us to save them. But there we stood, and there the new made banks and distant bluffs were dotted with men and families, but poor and partly dressed, deploring with dumb amazement the catastrophe in sight. The waters like a pall were spreading over all the inhabited lower parts of town and townsite. Nature shook about us. The azure meads of heaven were darkened as in death, and the fair Diana with her starry train, though defended by the majesty of darkness all around her, and by batteries of thick clouds in front, looked down on shuddering silence dimly, as lost in the labyrinth of wonder and amazement at the volume of the vast abyss into which we all expected to be overwhelmed. Next reeled the dear old office of the *Rocky Mountain News,* that pioneer of hardships and of honor, which here nobly braved the battle and the breeze for five full years and a month, regularly without intermission or intimidation, and down it sank, with its union flag staff, into the maelstrom of the surging waters. soon to appear and disappear, be-

tween the waves, as, wild with starts in mountains high they rose and rolled, as if endeavoring to form a dread alliance with the clouds, and thus consummate our general wreck.

Before this a few moments, one of the proprietors, Mr. J. L. Dailey, and four of the young gentlemen employees, who had been asleep in the building, awoke to realize the peril of their critical situation, and without time to save anything at all in the whole establishment, not even their trunks at their bedsides, or watches on the table-stands, they fortunately escaped by jumping out of a side window, down into the eddy water caused by a drift which had formed against the building, and thence by the aid of ropes and swimming, struck the shore, on the instant of time to see the sorrowful sight of their building, stock, material, money, all, even to the lot on which it stood, (for which all $12,000 would have been refused a few hours previously), uptorn, and yet scattered to the four winds of heaven, or sunk, shattered in sand banks between here and the States.

Higher, broader, deeper, and swifter boiled the waves of water, as the mass of flood, freighted with treasure, trees, and live stock, leaped towards the Blake street bridge, prancing with the violence of a fiery steed stark mad:

"Fierce as ten furies, terrible as hell."

Great God! and are we all "gone up," and is there no power to stem the tide, was asked all round. But no; as if that nature demanded it, or there was need of the severe lesson it teacheth to the citizens of town, the waves dashed higher still, and the volume of water kept on eroding bluffs and bank, and undermining all the stone and foundations in its rapid course.

The inundation of the Nile, the Noachian deluge, and that of Prometheus' son, Dencalion, the Noah of the Greeks, were now in danger of being out-deluged by this great phenomenon of '64.

Oh! it was indescribably and inconceivably awful to behold that spectacle of terrible grandeur, as the moon would occasionally shed her rays on the surges of the muddy waves, whose angry thundering drowned all other noise, and to hear the swooping of the death angel as he flew o'er the troubled surface, suggesting the idea of death and destruction in the wild tumults of the torrent!

Previous to this had gone towards the ocean-like delta of the creek and Platte, the Blake street bridge, General Bowen's law office, Metz's saddlery shop, F. A. Clark's and Mr. McKee's stores, the City Hall buildings and jail, together with Cass & Co.'s old Bank, Stickney's brick, and Tilton & Co.'s adjoining brick emporium, all with a crash and speedy disappearance in the current stateward bound, and with not a few people as passengers aboard. Now we see a youth, white with wan despair, and a child stiff in the cramps of death popping his head up stories high on the river's surface, only to be struck senseless by an overtaking tree

or solid sheet of water, thereafter thence, when the roaring of the raging elements, exemplification of the Almighty's voice and power, will toll their only funeral knell as calamity's sad corpse on sorrow's hearse is carried to its watery grave, with a watery winding-sheet and melancholy moonlight for its shroud! Verily, "the Lord giveth and taketh away," yet shall mortal man be more just than his maker?

FLOOD OF JULY 20, 1875

CHERRY CREEK REDIVIVUS

(*Rocky Mountain News*, July 21, 1875)

For a few days past the traditional dryness of Cherry Creek has been busted to the bedrock. Water, water has run everywhere, in its channel from the Divide to the Platte. But it came by fits and starts, like the lightning's style in Colorado. Last week's sun shone on Cherry Creek, and its sands glistened dryly as diamonds. Saturday night the creek was flooded in five minutes, and the steady tide of waters have been flowing ever since. Today it may subside, and quickly glow like a sandy furnace. Indeed, Cherry Creek is the most eccentric of Colorado's curiosities. Its freshets are like Homer's leaves on trees, which he compared to human races—

"They fall successive and successive rise."

There is a tide in the affairs of Cherry Creek, which, taken at the flood (like that last evening), leads on to fortune below Omaha. Today it may be dry as a whistle, while tomorrow it may rise to the swelling of the voiceful sea. So it did on the night of May 19, 1864, and so it tried to do last evening. But last evening it was not more than half as high as during that deluge of eleven years ago. Then it swept bridges, uprooted trees, drifted dozens of buildings, and drowned nineteen citizens in Denver. Then it was "on a high" sure enough, and continued so for a week, flooding the half of West Denver, and down on Blake Street to the corner of Fifteenth. Then, in the descriptive simile of Goldrick, it was "fierce as ten furies, terrible as hell."

Yesterday's phenomena ought to teach those savons a life lesson. We mean those scientific speculators who bloviated so much, for a few years past, about turning the bed of Cherry Creek, and telling that incorrigible old dame, thus far shalt thou go and no farther, unless at the peril of our city ordinances.

Really this last rise in Cherry Creek has been refreshing as a free circus, although death to the grasshopper and the truant sheep which were carried down here yesterday evening. Thousand upon thousand of our citizens were regular visitors to Cherry Creek for a few days past, but half the town were out last evening

to witness the sights, with their wives and sweethearts. Even the firemen, fearless of flames, were astounded at the flood.

CHERRY CREEK AND SOUTH PLATTE RIVER, MAY 22, 1876

(*Rocky Mountain News*, May 23, 1876)

The Platte has never, since the memorable freshet of '64, run so high or wide, or put on so many billows and frills, or tumbled about in such a turbulent style generally, as on yesterday. It was higher, to be sure—several feet higher—perhaps in 1864, but it was not able to work such destruction or devastation at that time as now. There wasn't so much town here in '64 as now, nor as many bridges, nor were there so many people then as now to crowd the banks and admire the old river as it bows its back on these periodical benders. Cherry Creek rose steadily all the afternoon, and showed no signs of subsidence until late in the night. In spite of the steady fall of rain and the immensity of slush under foot, there was the usual throng of spectators on shore. The old-timers were all there, of course, shaking their heads contemptuously and saying, "Shaw, it ain't a patchin' to the flood of '64; it ain't nowheres compared to that—you oughter been here and seen it, and then you might talk about high water." If there should come a freshet one of these days that would leave a high-water mark on the upper joint of the Lawrence Street tower, some fellow would stand on top of a house on Capitol Hill and swear that it wasn't "half as big a flood as that one in 1864." Until dark last night people gathered by hundreds on the bluff about the Larimer and Holladay Street bridges. There were women there ankle-deep in the slush of snow and mud.

A NEW MOVEMENT TO CONFINE, CURB OR CHANGE THE CHANNEL OF CHERRY CREEK

(*Rocky Mountain News*, June 1, 1876)

A large and enthusiastic meeting was held last night in the district court-room, to discuss the question of taking some action in regard to Cherry Creek. Speeches were made by General John Pierce, Judge Bennett, Engineer Lowrie, Colonel Powers, Mayor Buckingham, Thomas Anderson, F. B. Crocker, Judge Steck, and others, to the effect that the best interest of the city demands that immediate action be taken to either confine or change the channel of the creek, with a unanimous favoring of the latter plan. At the close of the meeting resolutions were unanimously adopted expressive of the spirit of the meeting, and requesting the City Council to call an election of the people for issuing of bonds to defray the

expense of straightening the channel of the creek. The resolutions read as follows:

"WHEREAS, The recent flood in Cherry Creek worked great damage to our citizens' property along both banks of the stream within the corporate limits of the city; that it washed away much valuable property in town lots above Lawrence Street, on the East Side, in its course; that it destroyed much value in buildings and private property; that it wrought much damage to public property on the bridges and their foundations at Colfax Avenue, Lawrence, Larimer, Holladay, and Blake Street crossings; that it overflowed its banks, and did much damage between Larimer Street and the Platte River on the West Side; that it endangered the lives and property of a large populous district of the city upon the West Side; that it menaced the safety and security of much of that portion of the city between Holladay Street and the Platte River—including the property along Blake Street to the American House, the buildings and machinery of the Holly Water Works, the City Gas Works, the three railroad depots—indeed, all that portion of the city below or east of the creek, built upon the Platte River bottoms lands, all of which lies lower than the bed of Cherry Creek at the Blake Street crossing; and

"WHEREAS, The said sudden and appalling flood, in addition to the visible damage done, has caused great fears throughout these large and populous districts of the city on both sides of the creek, of yet greater floods to come, and yet greater dangers to property and to human life, to follow in the future, and is causing still more pecuniary loss in the depreciating estimates of values which will be placed upon all property liable to the recurrence of such danger; and

"WHEREAS, It is now made apparent by the recent flood to all good citizens of this city that the strip of sand extending through the city from its southern boundary a distance of about two and a half miles, through and across a populous portion of the city, which is called Cherry Creek, but which contains little or no running water, except upon great occasions, as in the flood of 1864, 1875, and 1876, and which as a stream of water, for any purposes of utility to mankind within this city, is wholly and entirely worthless and valueless, and not only worthless, but an eyesore and a public nuisance—expensive and grievous to be borne even while suffered in its most endurable condition of drouth, and, when it moods, a most terrible and destructive monster, dangerous to life and property; therefore,

"*Resolved,* That Cherry Creek is neither useful nor ornamental to the city; that it is an expensive and dangerous nuisance in our midst, which should be abated.

"*Resolved,* That prompt action should be taken by the City Council to either abate the nuisance, if practicable, or afford better protection in the future to public and private property along its line by some thorough system to confine the floods to some certain channel.

"Resolved, That the consideration of this matter of Cherry Creek is one of grave public concern to every good citizen and taxpayer in the city.

"Resolved, That it is the sense of this meeting that the Mayor and Council call an election for the purpose of voting bonds as prescribed by the charter, with such time and amount as they may think best for the purpose of straightening the channel of Cherry Creek.

"(Signed) HIRAM P. BENNETT,
"FREEMAN B. CROCKER,
"JAMES M. STRICKLER,
"Committee on Resolutions."

FLOOD OF MAY 22, 1878

A full description of this flood appeared in the *Rocky Mountain News* the following day, as follows:

The recent "rise" in our municipal river has given rise to a perfect tidal wave of talk about "what shall be done with Cherry Creek?" The *News* regrets to hear, among other suggestions, the ancient cry in favor of an attempt to turn the creek out of its natural channel. Those who witnessed the fury of yesterday morning's flood would not have undertaken such a contract on the spot for any consideration. They would have been reminded of the old simile of trying to sweep back the Atlantic with a broom. If Cherry Creek was an ordinary, old-fashioned, down-east stream, carrying about so much water in winter and summer, it might do to talk about transplanting it, and perhaps as it is there is a way of doing it, but we are inclined to think the actual necessary expense of the undertaking, under the circumstances, would stagger our taxpayers terribly. We are speaking now, of course, of the expense of guarding against such floods as that of yesterday, and the most sanguine creek-turner must admit that provisions must be made against just such contingencies, if the creek is to be successfully turned. The question of expense thus becomes an effective barrier against the proposition, for we may safely assume that the taxpayers of Denver, a majority of whom are opposed to turning the creek, will not vote bonds for that purpose. What might be done, however, if a board of engineers should pronounce in favor of the plan, would be to divide Cherry Creek at the proposed point of divergence, and turn the current into the new channel without abandoning and closing up the present bed of the creek until it was fully demonstrated that the new channel was equal to every emergency, and not likely to damage persons or property contiguous to the banks. But this would be a costly experiment, and only strong faith in its success would induce people to take stock in it, and, pending the test of

its efficiency, the city would be little gainer either in expense of maintaining bridges or in the sense of security which we all covet in this matter. And this brings us to the question of security from the dangers and damages occasioned by these floods. Our bridges between East and West Denver are all gone, and some of them must be replaced, whatever else is done or whatever course is pursued in the future. But it's worse than useless to attempt to build a wooden bridge that can withstand such floods as that of yesterday morning, and the *News* favors the construction of cheap, temporary bridges for the present, until an iron bridge can be thrown across the creek above the highest high water. We say advisedly that pile bridges are a nuisance, not only because they go out with almost every flood, but for the more important reason that they catch all the floating timber and drift from above and form temporary dams which check the flow of water and sends it over the banks to flood the town, when without these obstructions the channel would carry the water away without damage to any one. As an eyewitness of the flood yesterday, the writer positively asserts that if there had been no bridges across the creek there would have been no water outside its banks above the Rio Grande crossing, and little damage to the banks themselves, if properly protected. To our mind this points to an easy and ready solution of the Cherry Creek conundrum—simply to clear the channel and guard the banks. We believe that, by throwing iron bridges of ample height and span across the creek and removing all others, the greatest floods could be carried away without danger, though it might be necessary to enlarge the channel at its narrowest part. These bridges, of course, will cost something when first built, but when we come to consider their security and durability, and their manifold advantages already indicated in this article, we cannot help but consider them an economical investment for the city. And should the creek be turned successfully hereafter, these bridges could be taken down and used elsewhere. Much has been said in derision of the attempt to protect the banks by piling and planking, but it must be remembered that the work was only begun and was not ready for any such test as that of yesterday, but, in spite of all this, it afforded considerable protection at various points.

FLOOD OF JULY 14, 1912

(Extract from *Denver Republican*, July 15, 1912)

DENVER SWEPT BY RAGING FLOOD
MANY DROWNED—LOSS $1,500,000

WALL OF WATER IN CHERRY CREEK COMES WITH ROAR—CLOUDBURST ISOLATES DISTRICT—RESCUE WORK HALTED BY DARKNESS

DEATH LIST TO BE COMPILED AT DAYLIGHT—500 GET SHELTER AND FOOD AT AUDITORIUM—CITY HALL MENACED BY RAGING TORRENT

Denver was inundated yesterday afternoon by a cloudburst that carried death and immense property loss—probably $1,500,000—in its wake.

Cherry Creek, usually a placid stream, became a raging torrent that swept over hundreds of homes and carried a score or more of them away.

Men, women, and children were drowned, but no authentic list could be obtained last night, because officials were unable to reach the stricken district.

At least 500 homeless were given shelter and care at the Auditorium last night. Mayor Arnold, acting through Fire Commissioner McGrew and Chief of Police O'Neil, threw the city's big building open for the refugees, and furnished coffee and bedding that was hastily collected. The Chamber of Commerce will forward the rescue work today and solicit subscriptions of money, food, and clothing.

Twenty-five babies were taken to the police matron and cared for by the officials. They were infants from six months to six years in age and had been separated from their parents in the flood excitement.

The storm broke at three o'clock and lasted two hours. During that time 2.08 inches of water fell and the wind reached a velocity of forty-eight miles an hour. The precipitation in twenty minutes of the period was one and one-half inches, and for five minutes .70 inch. The hurricane of wind and rain was confined almost exclusively to Denver.

It was not till near nightfall that Cherry Creek began to swell and roar with the sudden increase of water. There was but little time for the police officials to give warnings, and many of these were not heeded.

Within thirty minutes the creek-bed was filled to over-flowing, and half an hour later the water was rushing over the bridges

spanning the creek, and lapping into houses in the lowlands on either bank almost the entire five miles the channel runs through Denver.

The tramway cars were placed out of commission on a majority of the lines. Thousands at gardens and city pleasure resorts were marooned until after midnight.

Storm sewers were flooded and discharged their overflow into the streets. The damage suffered by the commission men on Market Street and in that district probably will run into the hundreds of thousands, counting damage to buildings and merchandise.

The Country Club golf links were inundated, and the championship tournament may have to be postponed till tomorrow.

The city streets and driveways were torn up by the rush of water, and not less than fifty miles of roadways are ruts and gulleys where they presented even surfaces yesterday.

Union Station was flooded to a depth of three feet, and incoming and outgoing passengers had to be transported to the street car or to the station on trunk trucks. At least 5,000 excursionists who arrived before the flood reached its full force escaped the inconveniences and dangers faced by at least 1,200 later passengers.

A large water main was broken by the undermining of the piping at about 10:30 o'clock, and as a result a large portion of what is known as the Capitol Hill district was without water last night. The water company placed a large force at work immediately to repair the break, and every effort is being made to have the supply on this morning.

Fire Commissioner McGrew stationed every chemical engine in the department in the waterless territory.

So numerous were the calls for medical attention received at police headquarters that a general call was issued to physicians. As a result, many prominent surgeons immediately volunteered their services and rendered valuable aid throughout the night.

Telephone, telegraph, and other public-service corporations suffered both temporary and permanent loss.

PRECIPITATION TABLES

MONTHLY AND ANNUAL PRECIPITATION, DENVER, COLORADO

(From Records of United States Weather Bureau)

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann'l
1872	0.55	0.22	0.91	2.09	3.74	2.07	2.69	1.75	1.57	0.68	0.69	0.29	17.25
1873	0.13	0.24	0.22	2.43	0.75	2.24	2.00	1.41	0.89	0.73	0.16	0.61	11.81
1874	0.84	0.53	0.49	1.70	2.43	1.21	3.35	0.68	1.34	0.64	0.08	0.17	13.46
1875	0.38	0.60	0.39	2.24	1.94	0.43	4.17	1.97	2.89	0.22	1.28	0.59	17.10
1876	0.21	0.11	1.80	1.22	8.57	1.10	1.16	2.03	0.60	0.12	1.50	1.70	20.12
1877	1.90	0.40	1.40	2.77	2.30	1.93	0.33	1.30	0.38	2.15	0.73	0.77	16.30
1878	0.10	0.48	1.82	0.05	2.90	2.78	1.33	2.25	1.23	0.80	0.67	1.05	15.46
1879	0.40	0.39	1.00	2.62	3.36	0.32	0.64	1.38	0.02	0.19	0.21	0.33	10.86
1880	0.38	0.32	0.21	0.31	1.11	1.22	1.38	1.46	0.89	1.37	0.83	0.10	9.58
1881	0.50	1.22	0.87	0.50	2.21	0.09	2.50	2.33	0.57	0.32	1.68	0.00	12.79
1882	0.57	0.20	0.20	1.47	2.98	4.96	0.66	1.20	0.06	0.75	0.71	0.73	14.49
1883	2.35	0.45	0.21	3.10	4.30	0.85	2.27	0.75	1.08	1.49	0.32	2.32	19.49
1884	0.22	0.86	0.93	3.33	4.61	1.47	0.65	1.71	0.13	0.21	0.19	0.76	15.07
1885	0.41	0.75	0.97	4.94	2.13	0.66	1.33	1.18	1.22	0.73	0.55	1.08	15.95
1886	0.62	0.72	2.36	2.79	0.09	2.26	0.50	1.62	0.98	0.33	1.93	0.87	15.07
1887	0.67	0.30	0.23	2.16	1.13	0.53	2.49	2.68	0.97	0.97	0.22	0.14	12.49
1888	0.11	0.37	1.15	1.71	2.66	0.29	0.41	1.51	0.11	0.77	0.33	0.09	9.51
1889	0.50	0.70	0.40	1.34	3.44	1.88	2.94	0.33	0.28	2.11	0.53	0.30	14.75
1890	0.18	0.46	0.35	2.50	2.01	T	0.79	1.89	0.17	0.64	0.30	0.04	9.33
1891	1.60	0.27	3.10	2.49	4.15	2.93	0.59	2.84	0.73	0.48	0.69	1.56	21.43
1892	0.40	0.75	1.20	1.75	2.14	1.33	1.19	0.58	T	3.92	0.44	1.32	15.02
1893	0.05	0.83	0.23	0.87	3.09	0.13	1.14	0.35	0.05	0.84	0.55	0.35	8.48
1894	0.18	0.90	0.70	3.30	3.00	0.39	2.11	1.86	1.55	0.19	0.22	0.69	15.09
1895	0.32	0.48	1.19	1.19	2.86	2.65	4.28	0.76	0.98	1.13	0.27	0.01	16.12
1896	0.25	0.24	1.43	0.93	1.27	0.89	2.80	0.97	1.81	0.84	0.10	0.31	11.84
1897	0.58	0.82	0.90	1.31	3.15	2.16	2.06	1.44	0.44	1.64	0.24	0.63	15.37
1898	0.20	0.68	0.28	1.20	4.88	0.94	0.67	0.96	0.28	1.05	0.85	0.99	12.98
1899	0.65	0.58	1.10	0.75	0.15	0.47	1.92	1.78	0.20	1.01	T	0.72	9.33
1900	0.13	0.55	0.63	8.24	0.53	1.87	1.30	0.05	0.87	0.33	0.37	0.42	15.29
1901	0.05	0.06	0.88	1.96	1.18	2.09	0.01	1.30	0.22	0.46	T	0.89	9.10
1902	0.17	0.38	0.63	0.60	1.98	1.89	1.24	0.76	3.70	0.80	0.61	0.59	13.35
1903	0.12	0.42	0.87	0.81	0.75	1.62	1.36	1.35	0.56	1.34	0.07	0.23	9.50
1904	0.04	0.17	0.94	0.74	3.27	3.54	2.13	0.60	1.77	0.40	0.04	0.41	14.05
1905	0.99	0.35	3.07	4.95	2.65	0.61	1.55	0.67	0.49	2.31	0.04	T	17.68
1906	0.17	0.06	1.88	3.67	1.45	1.51	1.21	0.88	2.72	1.98	1.30	0.01	16.84
1907	0.46	0.33	0.54	2.91	2.93	1.15	1.52	0.23	0.74	0.17	0.40	0.45	11.83
1908	0.53	0.04	0.11	0.39	2.82	1.68	2.09	3.19	0.80	1.90	1.74	0.63	15.92
1909	0.21	1.35	3.03	2.59	1.74	1.70	4.17	2.13	3.78	0.28	1.10	0.88	22.96
1910	0.16	0.35	0.96	1.38	2.50	0.20	3.47	1.79	1.00	0.21	0.16	0.71	12.89
1911	0.12	0.68	0.28	1.41	0.52	0.56	1.31	1.08	0.75	0.33	0.37	0.34	7.75
1912	0.12	1.34	0.87	0.89	4.18	2.27	2.90	1.07	2.01	1.69	1.14	0.45	18.93
Mean	0.45	0.51	1.00	2.04	2.53	1.44	1.77	1.38	0.99	0.34	0.58	0.59	14.21

DAILY PRECIPITATION AT DENVER, COLORADO, 1912

Day	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.
1	0	0	.03	0	0	0	.02	T	T	T
2	0	0	T	0	0	0	0	0	T	0
3	T	T	T	0	.05*	0	.34	T	0	0
4	0	0	.04	0	.04*	0	.10	0	0	0
5	0	.03	0	0	0	0	0	0	0	T
6	T	0	0	0	0	T	0	.01	0	T
7	.01	0	.03	0	T	T	T	.03	0	0
8	0	0	T	0	.10	.04	0	0	T	T
9	0	0	0	0	.01	.02	0	0	.48	T
10	0	T	.05	0	1.10	0.32	T	.01	T	.84
11	.01	0	.02	0	.24	T	0	0	.01	.03
12	0	0	0	T	.63	.02	T	T	.05	0
13	0	0	.13*	0	1.42	0	.18	T	.24	0
14	0	0	.06*	0	0.10	.05	2.00	.42	.61	0
15	0	.01	0	.01	T	.14	T	T	.01	0
16	0	.01	0	0	0	.19	0	.01	0	0
17	.02	0	0	.29*	0	1.10	0	.16	0	0
18	0	.05	0	.31*	0	.01	.02	0	0	0
19	0	.20*	.17*	.06	0	0	T	T	.09	T
20	0	.06*	.26*	.03	0	0	0	0	.09	.13
21	0	0	0	.04	0	T	.01	0	0	.38
22	0	0	0	T	0	0	.02	0	0	0
23	0	.17*	.04	0	0	0	T	0	.10	0
24	0	.52*	0	0	T	0	.07	0	.27	0
25	0	.15*	0	T	0	0	.02	0	0	0
26	0	0	.01	.10	0	0	T	0	0	0
27	.06	T	T	.05	0	T	T	T	0	T
28	0	.09	0	0	0	0	T	.05	.02	0
29	0	0	0	0	0	T	.06	T	.04	0
30	0	....	.01*	0	T	.38	.05	.38	0	*.22
31	.02	....	.02*	....	.49	....	.01	0	....	.09
Total	0.12	1.34	0.87	0.89	4.18	2.27	2.90	1.07	2.01	1.69

* Estimated.
T indicates trace of precipitation.

MAXIMUM PRECIPITATION IN TWENTY-FOUR HOURS

(From Records of United States Weather Bureau, Denver, Colorado)

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann'l	Date of Maximum of Year
1872	0.33	0.09	0.35	0.92	1.18	1.12	1.76	0.77	0.90	0.40	0.40	0.13	1.76	July 11–12
1873	0.07	0.08	0.14	0.70	0.24	1.76	1.42	0.87	0.72	0.34	0.06	0.37	1.76	June 8–9
1874	0.48	0.31	0.20	1.06	1.42	0.70	2.00	0.22	0.57	0.21	0.04	0.13	2.00	July 20–21
1875	0.12	0.48	0.48	0.90	0.94	0.18	1.05	0.81	0.91	0.14	0.34	0.53	1.05	July 4
1876	0.19	0.04	1.03	0.70	6.53†	0.44	0.70	0.85	0.49	0.12	0.90	0.50	6.53	May 21–22
1877	0.75	0.20	0.55	0.90	0.92	1.28	0.21	1.00	0.19	0.45	0.60	0.58	1.28	June 7–8
1878	0.10	0.17	0.42	0.05	1.47	0.67	0.50	1.06	0.61	0.71	0.30	0.45	1.47	May 6–7
1879	0.18	0.23	0.72	0.97	1.71	0.16	0.32	1.01	0.02	0.17	0.13	0.13	1.71	May 11–12
1880	0.21	0.11	0.10	0.14	0.42	0.69	0.76	0.48	0.86	0.34	0.31	0.09	0.86	Sept. 25
1881	0.17	0.67	0.40	0.35	0.81	0.09	1.60	0.77	0.40	0.16	0.48	0.00	1.60	July 30
1882	0.39	0.10	0.20	0.43	1.15	1.82	0.28	0.78	0.05	0.33	0.39	0.28	1.82	June 10–11
1883	1.22	0.40	0.15	0.72	2.02‡	0.33	0.78	0.25	0.46	0.98	0.29	1.75	2.02	May 8
1884	0.14	0.60	0.37	1.74	1.60	0.61	0.12	1.03	0.08	0.16	0.13	0.34	1.74	April 18–19
1885	0.24	0.39	0.24	2.79*	0.92	0.38	0.25	0.58	0.53	0.45	0.28	0.48	2.79	April 22–23
1886	0.29	0.34	0.67	0.89	0.03	1.55	0.26	1.13	0.94	0.28	0.90	0.42	1.55	June 2
1887	0.34	0.22	0.08	1.26	0.85	0.15	1.05	1.38	0.39	0.56	0.14	0.05	1.38	Aug. 23–24
1888	0.06	0.26	0.52	1.07	0.82	0.10	0.14	0.79	0.08	0.50	0.24	0.05	1.07	April 27–28
1889	0.20	0.49	0.34	0.57	2.08§	0.99	1.18	0.25	0.15	0.91	0.21	0.22	2.08	May 9–10
1890	0.08	0.28	0.26	1.28	0 72	T	0.58	0.62	0.10	0.52	0.16	0.03	1.28	April 24–25
1891	0.86	0.19	1.28	0.88	2.02	1.32	0.22	1.05	0.24	0.31	0.28	0.62	2.02	May 20–21
1892	0.19	0.32	0.64	1.10	0.63	0.89	0.32	1.05	T	2.58	0.44	0.54	2.58	Oct. 12–13
1893	0.04	0.46	0.16	0.41	1.41	0.08	0.44	0.36	0.03	0.51	0.16	0.12	1.41	May 5–6
1894	0.10	0.50	0.23	1.84	1.15	0.22	1.16	0.24	1.44	0.19	0.17	0.40	1.84	April 30
1895	0.17	0.25	0.80	1.07	1.60	1.16	1.62	1.21	0.96	0.88	0.22	0.01	1.62	July 30
1896	0.12	0.13	0.75	0.52	0.67	0.25	1.24	0.65	1.03	0.42	0.09	0.30	1.24	July 24–25
1897	0.50	0.22	0.40	0.48	1.41	1.06	0.94	0.76	0.37	1.12	0.12	0.31	1.41	May 27
1898	0.15	0.61	0.10	0.60	1.25	0.33	0.23	0.59	0.13	0.54	0.32	0.40	1.25	May 27
1899	0.24	0.27	0.63	0.35	0.06	0.40	0.45	1.32	0.20	0.32	T	0.36	1.32	Aug 2–3
1900	0.11	0.18	0.27	1.66	0.20	1.17	1.09	0.02	0.58	0.30	0.36	0.27	1.66	April 14–15
1901	0.05	0.03	0.28	1.16	0.36	1.77	0.01	0.53	0.21	0.26	T	0.44	1.77	June 14–15
1902	0.08	0.16	0.42	0.40	1.05	1.16	1.08	0.21	2.70	0.36	0.31	0.36	2.70	Sept. 20–21
1903	0.10	0.16	0.69	0.29	0.39	0.60	0.47	0.64	0.21	0.86	0.04	0.14	0.86	Oct. 29–30
1904	0.02	0.17	0.30	0.60	1.56	2.03	0.95	0.28	0.92	0.39	0.02	0.37	2.03	June 3
1905	0.62	0.13	1.56	2.30	0.63	0.18	0.82	0.54	0.28	1.00	0.02	T	2.30	April 23–24
1906	0.09	0.04	0.59	2.00	0.41	0.97	0.62	0.37	0.62	0.68	0.99	0.01	2.00	April 26–27
1907	0.24	0.20	0.52	1.44	0.58	0.83	0.97	0.13	0.28	0.12	0.33	0.27	1.44	April 19–20
1908	0.50	0.04	0.10	0.16	1.02	1.32	0.74	0.70	0.76	1.24	1.09	0.28	1.32	June 14–15
1909	0.16	0.88	2.43	1.26	0.64	0.49	1.53	0.60	1.94	0.16	0.47	0.41	2.43	Mar. 23–24
1910	0.15	0.15	0.96	0.63	1.04	0.10	2.44	0.73	0.51	0.15	0.08	0.39	2.44	July 28–29
1911	0.11	0.34	0.12.	0.46	0.22	0.53	0.49	0.67	0.27	0.27	0.20	0.12	0.67	Aug. 10–11
1912	0.06	0.56	0.43	0.60	1.42	1.24	2.10	0.42	0.79	0.87				

Maximums—1872–1912

	1.22	0.88	2.43	2.79	6.53	2.03	2.44	1.38	2.70	2.58	1.07	1.75	6 53
	31	22	23–24	22–23	21–22	3	28–29	23–24	20–21	12–13	28–29	5–6	5/21–22
	1883	1909	1909	1885	1876	1904	1910	1887	1902	1892	1883	1883	1876

* 2.79 inches, April 22-23, 1885. † 6.53 inches, May 21-22, 1876. ‡ 2.02 inches, May 8, 1883. § 2.08 inches, May 9-10, 1889. July 21-22, 1874, 2.00 inches.

CASTLEWOOD RESERVOIR

Detailed descriptions of the Castlewood Reservoir are given in a number of different articles, among which may be mentioned the following:

Engineering Record, numbers of December 24, 1898; February 9, 1899; April 29, 1899; May 19, 1900.

Annual Records of the United States Geological Survey, 13-03, page 302; 20-04, page 280.

Wilson's "Irrigation Engineer," page 394.

Schuyler's "Reservoirs for Irrigation," page 36.

Wegmann's "The Design and Construction of Dams," page 275.

Furthermore, special reports concerning the Castlewood Dam have been made by a number of engineers of the city of Denver and state engineers of Colorado. Among these reports may be especially mentioned:

The report, dated March 15, 1890, by J. P. Maxwell, state engineer, and Donald W. Campbell, consulting engineer.

The report, dated May 12, 1891, by H. F. Meryweather, Donald W. Campbell, and J. P. Maxwell.

John B. Hunter, then city engineer of Denver, also made a report, dated August 14, 1897. At this time a number of prominent engineers visited Castlewood Dam and reported its condition. It was the consensus of opinion at that time that the dam was then unsafe, and repairs were recommended, which for the most part have been made. The following description is taken from Wegmann's "The Design and Construction of Dams" (fifth edition), pages 275 to 277:

The Castlewood Dam, Fig. 65, was built across Cherry Creek, about thirty-five miles south of Denver, Colorado, to store water for irrigation. This stream is liable to great changes of flow. Ordinarily its volume is very small, but during sudden freshets, following so-called cloudbursts, it discharges as much as 10,000 cubic feet per second.

The dam was begun in December, 1889, and completed in November, 1890. It is 600 feet long on top and 8 feet wide. Its maximum height is about 70 feet above the surface and 92 feet above the foundation. This dam differs from all the other rock-fill dams we have described, in having a facing of rubble laid in cement mortar at its inner and outer slopes. Between the face-walls the dam consists entirely of loose stone dumped on the natural surface.

The inner face-wall is 4 feet thick and is carried up on a batter of 1 foot horizontal to 10 feet vertical, except at the highest part of the wall at the overflow, which is placed in the middle of the dam, where the inner wall for a stretch of 120 feet was made vertical on the side next to the rock-fill. The foundation trench for the inner wall was excavated in an arenaceous clay, containing large boulders, to a depth of 6 to 22 feet.

The outer face-wall is carried up in steps on a general slope of 1 to 1. Its foundation is nowhere more than 10 feet below the surface. The steps were formed of dimension-stone, which extend at least 3 feet into the dam. Both the inner and outer face-walls rest on footing courses of concrete 1 to 2 feet thick.

The face-walls are carried up on the slopes mentioned to the elevation of the spillway, where they are united. The top of the dam is formed of a wall of rubble masonry, 8 feet wide and 4 feet high, having vertical faces.

The overflow, which is placed in the middle of the dam, is 100 feet long by 4 feet deep. In addition to this, a by-pass 40 feet wide is provided on the west side of the dam, and aids in discharging the surplus water. Its floor and sides are lined with masonry to a safe point of discharge.

The outlet well is built in the center of the dam adjoining the overflow weir. It measures, on the inside, 6 x 7½ feet. The walls of the well are 4 feet thick, except towards the reservoir, where the thickness of the wall is increased by offsets to 10 feet at the surface. As these offsets are made on the inside of the well, to provide a foundation for the valves controlling the inlet pipes, the opposite wall is recessed out to maintain the inner dimension of the well. Where the recesses are made, the wall is supported by arches. Eight 12-inch inlet pipes, placed in pairs at four different elevations, admit the water to the well, from which it is conveyed by a 36-inch concrete conduit and discharged into the creek a short distance below the dam.

The Castlewood Reservoir covers 200 acres of land and stores about 4,000,000,000 U. S. gallons. It was built for the Denver Land and Water Company according to the plans prepared by their chief engineer, Mr. A. M. Welles. The plans contemplated placing an earthen slope against the inner face of the dam to a certain height. This was not done, however, until later, after the dam commenced to leak badly. The contract for the work was given to the Rosenfeld Construction Company, who employed their own engineers. Although the Denver Land and Water Company had inspectors on the ground, the work appears not to have been well executed in some particulars. Settling occurred at some points, causing cracks 2 to 4 inches deep, through which the water found an outlet. At one point the water appears, also, to have flowed under the dam.

The dam was repaired and an earthen slope placed at its up-stream face. The top of this bank is 35 feet below the crest

of the dam at the center, and rises gradually so as to reach the crest at both ends of the dam. This slope is covered by a riprap 1 foot thick. Where the leakage occurred clay puddle was placed next to the inner wall.

The plans of the Castlewood Dam have been severely criticised, especially the fact that the inner face-wall, where only 4 feet thick, overhangs the loose rock-fill, its center of gravity falling outside its base. Eight years of service have, however, not yet shown any disadvantage resulting from this feature. Engineers will be interested in watching the future history of this dam.

To the data contained in the above description should be added certain facts, as follows:

The dam has now stood for about eighteen years without giving way, excepting for leaks under the dam. The earth embankment inside the dam has been raised so that its crest is practically at the level of the spillway of the dam throughout its entire length. The present capacity of the reservoir is approximately 4,000 acre-feet. Plans are contemplated, however, with a view to increasing the capacity so that its total capacity would be approximately 6,000 acre-feet. Connected with the same irrigation system are other reservoirs, already constructed and now in process of construction, with capacities estimated roughly at 2,000 acre-feet. The Commission does not believe that under any probable conditions these dams are likely to break, and no concern should be felt on that score. With such a great run-off, however, as seems to be possible, there is a possibility that these reservoirs might go out, and some consideration should be given to this possibility in providing for perfect safety. However, the public need feel no concern whatsoever as to any or all of these reservoirs going out and doing any damage within the city, excepting in conjunction and combination with such an extraordinary flood as has been spoken of as possible. If they should all go out together after the main flood had passed, or independently of such a flood, the people of Denver would know nothing of it excepting by report. Nothing that is contained herein should be construed as a criticism of the Castlewood irrigation system, which the Commission believes to be an important asset to Denver, both on account of its furnishing water for irrigation, and as acting, in an important degree, as a flood regulator.

REPORT OF COMMITTEE APPOINTED BY CHAMBER OF COMMERCE TO ASCERTAIN THE MOST DESIRABLE METHOD OF PREVENTING DAMAGE TO THE RESIDENCE AND BUSINESS PORTIONS OF DENVER BY CHERRY CREEK FLOODS

In conducting this investigation, your committee has carefully considered the channel of Cherry Creek from Parker to its confluence with the Platte, and has followed the latter stream very closely from Littleton to Riverside. All of the bridges and crossings within this area have been carefully examined, the waterways underneath them measured, and the effects of the flood and the depth to which these bridges were submerged noted. In the collection of other data, we are indebted to the State Engineer for the records giving the flow of the Platte and Cherry Creek during the flood; to the United States Weather Bureau for records of rainfall; to the City Engineer for the grades of Cherry Creek and the Platte; and to the Denver Water Works Company for surveys of Cherry Creek channel, underflow, distance to bedrock, etc.

While the time and means at our disposal were entirely insufficient for an examination so comprehensive as this will have to be before it is concluded, we have endeavored to make the best possible use of the data and information at our disposal.

A great many measures for the prevention of damage to the city from Cherry Creek floods have been proposed, but only a few of them seem of sufficient importance to require special investigation.

First—A storage dam on Cherry Creek, at some convenient point above the city, large enough to hold all of the waters liable to accumulate during any single downpour.

Second—A storage dam, similarly located, sufficiently large to hold from one-half to two-thirds of the maximum flood waters, the remaining portion being permitted to pass on and reach the Platte through the present bed of Cherry Creek.

Third—A number of small dams on the tributaries of Cherry Creek, and a small dam on the main stream just above the highest tributary dammed.

Fourth—A diversion dam across the channel of Cherry Creek, about seven and one-half miles above its confluence with the Platte, and a channel sufficiently large to carry the flood waters of Cherry Creek eastward over into Sand Creek channel, from

which they would naturally find their way to the Platte without doing serious damage.

Fifth—A diversion dam across Cherry Creek, near the proposed location of No. 4, and a canal running to the westward and discharging the flood waters of Cherry Creek into the Platte River near its entrance into the city of Denver.

Sixth—Changing the course of Cherry Creek from the west end of the Country Club ground to the Platte River by cutting a straight channel due west to the river.

Seventh—Enlarging the present Cherry Creek waterway sufficiently to permit it to carry off the floods without damage to residential or city property.

To ascertain which of these plans will give the maximum efficiency at the lowest cost, it will be necessary to make preliminary surveys and estimates, as well as to sink lines of test holes across the bed of Cherry Creek in various places in order to determine the depth to which dams, either diversion or retaining, would have to be carried.

There are many arguments pro and con in favor of each of these projects.

The first plan, which necessitates the erection of a storage dam on Cherry Creek, will probably be subject to two objections: First, the difficulty of obtaining suitable foundations, and the great width and height of the dam. Second, the fall of Cherry Creek, averaging, as it does, about twenty-five feet to the mile, would necessitate the use of quite a high dam to hold and impound any considerable amount of water; in addition to which this high grade permits the stream to carry an enormous amount of gravel and sediment, which in a very few years would partially, or perhaps completely, fill the dam. As an example of this we have only to notice how quickly the small dams across the channel of Cherry Creek become filled with sand after they have been excavated and cleaned out.

The second plan, involving the use of a storage dam sufficiently large to hold from one-half to two-thirds of the maximum flood waters, would be subject to the same objections as the first, plus the fact that it would have to be equipped with control gates; otherwise no water would pass down Cherry Creek until the dam was filled, and after that the channel below would have to carry the full volume of the flood. To obviate this, the dam should be fitted with control gates, so that only as much water as

the present Cherry Creek waterway could handle safely would be permitted to escape; but this outflow should begin at the commencement of the flood, so that the retention dam would only be compelled to carry the surplus, and at the same time the capacity of the waterway below should not be exceeded.

The third plan, necessitating the use of a number of small dams, would be extraordinarily expensive and would not afford the same protection as the first and second, because the dams on each of the tributaries would have to be sufficient to carry the maximum precipitation on that particular stream, whereas a dam on the main stream would only be called upon to take care of the aggregate flow from all of the tributaries.

The fourth plan, necessitating the use of a diversion dam across the bed of Cherry Creek and a carrying canal, running eastward, sufficiently large to carry the flood waters over into Sand Creek channel, has been considered for a great many years, but, while a number of surveys have been made, none of them have gone into detail sufficiently to enable the cost of this very desirable plan to be determined within reasonable limits.

The fifth plan, which also necessitates the use of a diversion dam across Cherry Creek channel and a carrying canal, running westward, to transport the flood waters into the Platte River at a point just south of the city limits, has not been under consideration so long as the fourth plan, but it is easy to see that the cost of the diversion dam would be the same as No. 4, while the canal, owing to its shorter length and less average depth, would cost somewhat less. On the other hand, it would discharge the flood waters into the Platte River above the city of Denver, and if this occurred at a time when the Platte River was running full, the combined flood of the Platte and Cherry Creek might occasion almost as much damage as the recent flood. The fall of the Platte River is only thirteen feet to the mile, while Cherry Creek has a fall of twenty-five feet per mile, which means that, to carry off the same volume of water in a given time, the cross-section of the waterway on the Platte River would have to be very much greater than on Cherry Creek.

The sixth plan, while at first it appears somewhat radical, would shorten the length of Cherry Creek between the Country Club and the Platte River 50 per cent and would have the additional advantage that it would cross all of the streets at right angles, thereby facilitating bridging, and at the same time run through a less valuable portion of the city than is now traversed

by that erratic stream. It would also avoid the maze of railroad tracks and obstructions covering the channel below Wazee Street. The objections to this scheme is that the flood waters of Cherry Creek would be delivered into the Platte 16,000 feet farther up-stream than at the present, thus subjecting about three miles more of the Platte bottoms to the action of Cherry Creek floods.

This would probably not prove a very serious matter, as the obstructions in the way of pile bridges and crossings above the present mouth of Cherry Creek are very few in number as compared with those below, and but slight expense would be entailed in replacing the low-level, pile-supported street crossings with bridges of sufficient span to carry the increased flow.

The seventh plan, enlarging the present Cherry Creek waterway to a size which would enable it to carry Cherry Creek floods without damage to city or residential property, is the natural, and perhaps the safest, method of meeting the difficulty.

As no change in the point at which Cherry Creek discharges its waters into the Platte would be made, there would, of course, be no claims made for damages; neither would it be necessary to condemn any property for necessary right of way, except perhaps in a few places where the additional size of channel required would exceed the width of the ground now owned by the city. Under this system there would be no danger to the city from the bursting of dams, due either to leakage or overloading. On the other hand, it would necessitate the widening of the present channel, raising the bridges, and the substitution of "through" for "deck" bridges wherever the latter are used, which might make the ultimate cost higher than some of the other plans.

Walling in the sides of the stream within the city limits, reducing its bed to a uniform grade, and lining it with concrete, would not only prevent scouring and undercutting the walls, but would increase the velocity, thus reducing the cross-section required to carry a given volume of water.

The rainfall, as shown by the records of the United States Weather Bureau, in Denver on Sunday, July 14, 1912, amounted to 2.08 inches, which fell between 3:30 and 7:30 p. m. At Castle Rock the precipitation was 1.65 inches, which fell between 5 p. m. on Sunday and 7 o'clock the following morning. At Colorado Springs the rainfall commenced at 5:30 p. m. and continued until 6:30 the following morning, and amounted to 1.09 inches. Castle Rock and Colorado Springs, though not included in the Cherry

Creek drainage area, are sufficiently close to it to afford a fair indication as to the amount of rainfall and the period during which it fell. The heaviest precipitation at Denver occurred between 3:35 and 3:50 p. m., when the recording rain-gauge gave a record of 1.35 inches. If this excessive downpour had been continued for even a slightly longer period, it is easy to see that the flood would have been greatly intensified, as the percentage of run-off increased very rapidly with the rate of precipitation.

The water-level gauge chart taken at Sixteenth Street July 14 and 15 shows that the rise of the Platte due to the heavy local rains began at 3:15 Sunday afternoon and increased very rapidly until 4:15; then remained practically stationary until 8 p. m., when the heavy flood began to roll down from Cherry Creek. From this time on the chart line runs up by leaps and bounds, until the maximum was reached at 11 p. m., when it began to fall off slightly for three-quarters of an hour, after which it dropped rapidly back, reaching the level of the afternoon before at 4 a. m. on the morning of the 15th. In other words, disregarding the increase due to local rains, the big flood in Cherry Creek lasted from 7 p. m., July 14, to 4 a. m., July 15—a period of nine hours. The run-off from 7:45 p. m., July 14, to 6 a. m., July 15—ten and one-quarter hours—averaged 5,100 second-feet and amounted during that period to 4,320 acre-feet.

The Cherry Creek drainage area has a length of forty-four miles, an average width of nine and one-half miles, and an area of 410 square miles. From the head of the watershed, which extends to within fifteen miles of Colorado Springs, to its junction with the Platte, it has a fall of 2,400 feet. The grade of the lower portion of the stream near Denver is about twenty-five feet per mile, but farther up this grade is more than doubled, which accounts for the large amount of sand brought down during periods of high water. The flow of sand is, however, by no means limited to floods, as even at low-water stages it can be seen slowly rolling down the stream.

When the early settlers of Denver began to build in the channel of Cherry Creek, the Indians, who were always close observers, warned them that "Big Water would come;" but no heed was given to their caution, and the city began to grow, not only on the banks, but even in the dry bed of the creek.

The first Cherry Creek flood of which we have any record occurred on May 19, 1864. The water reached its maximum

height about midnight, the period of high water lasting about five hours. The lower portion of the city, which at that time was almost entirely built near the bed of Cherry Creek and in the Platte bottoms, was submerged to a depth of from one to five feet, and in some of the lowest houses there was as much as six feet of water over the floors.

The City Hall, which stood on the banks of Cherry Creek at Blake Street, and the *Rocky Mountain News,* which was located on posts in the creek-bed on the line of Market Street, were both completely swept away. The city safe and the *Rocky Mountain News* printing-press both disappeared out of sight in the sand; the latter was dug out many years later, about twelve feet below the surface, in some excavations which were being made for foundations, but the city safe has not yet been uncovered.

The flood had its origin in an extremely heavy rainstorm, accompanied with hail, which occurred on the afternoon of the 19th. The rainfall had also extended to the drainage system of the Platte, and that river had risen to an unprecedented height. The combined waters of the two flooded the lower portion of the city completely. On Blake Street, near Cherry Creek, the water had a depth of one foot. Eight lives were lost during the flood, and several hundred thousand dollars' worth of property destroyed.

The second flood, not quite so great in extent, occurred on the night of July 20, 1875, being occasioned, as in the case of that of May 19, 1864, by a tremendously heavy rain on the day before.

The third flood occurred on the night of May 2, 1878, and, old residents claimed, was nearly equal in volume to that of 1864.

The occurrence of these last two floods in such quick succession aroused the people of Denver to the necessity of doing something to prevent damage in the future, and on November 24, 1878, the City Council adopted the plan of cutting a channel from a point a mile above the Broadway crossing on Cherry Creek to Archer Lake. A contract was let for digging a twenty-five-foot waterway for the sum of $100,000; $42,000 to be paid in cash, and the balance to be paid from the sale of lots reclaimed from Cherry Creek; but legal complications ensued, and the work was never even commenced.

Later the proposition was taken up again, and the citizens voted on a plan to issue $75,000 in bonds to cover the expense, but

it failed to carry. The same scheme was tried again, and lost, a year or two later.

The maximum amount of water liable to pass through the channel of Cherry Creek at Denver, while primarily controlled by the rate of precipitation, may be very materially affected by other factors. For instance, if a heavy rainstorm should travel slowly up the line of Cherry Creek, it is easy to see that the water which first fell would have an opportunity to run off and be discharged through the city before the rainfall from the upper portions of Cherry Creek, which fell at a considerably later period, would have time to reach the city; but should the travel of the area of maximum precipitation be in the opposite direction, it is easy to see that it might travel down-stream at the same rate of speed as the wall of flood water, and the result of this would be that the water from upper and lower portions of Cherry Creek would reach Denver simultaneously, and would thereby give a flood of much greater intensity than if the storm had been traveling in the opposite direction. There is an old engineering axiom to the effect that "what may happen will happen." Therefore, it would be wisdom on the part of the city of Denver to make preparations for handling even a greater flood than that of Sunday, July 14, 1912.

The maximum volume of water, or peak of the flow, has been variously estimated, but, judging from the data taken by well-trained observers and the figures from the state recording gauge on the Platte River, under the Sixteenth Street bridge, just below the discharge of Cherry Creek, it would seem that it must have been in the neighborhood of 12,000 cubic feet per second. Considering the conditions above described, it would seem that we should have at least a factor of safety of 50 per cent, which means that, whatever plan is adopted, provision should be made for taking care of at least 18,000 cubic feet per second, or three times the amount that could flow under most of the bridges which at present span, but unfortunately also obstruct, Cherry Creek. The waterway under many of them is ridiculously small, and in most instances no attempt has been made to give the maximum amount of waterway possible at even the present difference of level between the surface of the streets and the bottom of the channel.

Many of the bridges, both plate and open girder, are deck or partial deck, and even where through bridges—the only type

which should ever be used under these conditions—are employed, no effort has been made to minimize the distance between the roadway and the bottom of the bridge. In many of them the floor beams are carried above the pin connections, and the lower chord projects two or three feet down into the channel, thereby dangerously obstructing it.

The worst possible combination is reached just below the City Hall, where the plate-girder Blake Street deck bridge is joined at right angles, midway across the stream, by the Fourteenth Street bridge of the same type. The girders project so far below the surface of the roadway that they only leave a seven-foot waterway underneath, the cross-section of which is further reduced by circular piers in the center of the channel, thus affording one of the most efficient devices for catching debris and choking up the constricted channel that could readily be constructed. Judging from the accounts of observers and the appearance of the channel below these bridges, it seems clear that logs, trees, and other debris practically choked up the space under these two bridges, so that they really formed a diversion dam instead of a waterway, flooding the entire lower portion of the city.

Spanning the bed of Cherry Creek from above the Country Club to the Platte River, there are but few bridges in the design of which any regard for waterway clearance and possible floods has been shown.

Below the Blake Street bridge a series of railroad bridges cross Cherry Creek, none of them having much more than sufficient waterway for the flow from an ordinary rainstorm, to say nothing of a cloudburst. In addition to these obstructions, there is a street roadway on Delgany Street crossing the bed of Cherry Creek on piles, so that it may be said that the bed of the stream is restricted by both horizontal and vertical obstructions, thereby forming a complete maze in which flood-carried timber and debris are certain to be entangled and choke up the channel.

Singularly enough, there are very few real bridges crossing the Platte River, the majority of both highway and railroad crossings being merely roadway carried on rows of piles. At one place, just below the Nineteenth Street bridge, there are two railway tracks crossing the stream close together and carried on not less than 200 piles. At some places where the railroads have skew crossings they have not even taken the trouble to put the

bents of piles in line with the stream, but have put them in at right angles to the tracks, without the slightest regard for the waterway beneath.

The new bridge on the Moffat Road just below the stockyards is so close to the water level that it was completely overflowed by the flood, and on the forenoon of the 23rd the water was only about three feet below its floor beams.

If Plan 5, 6, or 7 should be adopted, it will be necessary, to prevent damage to the lower portion of the city, to remove all obstructions from the channel of the Platte River below the point at which Cherry Creek empties into it.

Contrary to general belief, there is nothing unusual or phenomenal about Cherry Creek floods. All similarly situated drainage channels, including the different dry creeks from Cherry Creek to Bijou in northeastern Colorado, are subject to recurrent floods, the volume of which is roughly proportional to their grade and drainage area. Quite recently both Sand Creek and Box Elder have been on a rampage, and the only reason that greater damage was not occasioned by their floods was that they ran through open channels, with nothing to oppose their rush except a few ditch flumes and bridges, instead of flowing through a populous city.

The rainfall of July 14 of this year is by no means the maximum that may be expected, as the records of the United States Weather Bureau, extending back to 1872, show that in Denver the maximum precipitation in twenty-four hours has reached 6.53 inches.

Most streams, whether surface-flowing or dry, are subject to floods, but the latter class are by far the most dangerous, because during their long periods of inactivity people are lulled into a false sense of security and encroach on their storm channels, forgetting that a time is coming when the maddened stream will again demand its right of way. So long as the climate, topography, and rainfall of this portion of Colorado remain unchanged, so long must occasional floods in Cherry Creek be expected, and ordinary business prudence demands that adequate provision be made for taking care of them.

Until further information and data are obtainable, your committee does not feel justified in selecting any particular plan, but it is reasonably certain that comparatively inexpensive preliminary surveys and estimates will eliminate four or five of the

proposed schemes, so that the more costly final surveys and estimates will not be necessary on more than two or three of them.

To summarize our conclusions:

First—Floods must be expected at irregular intervals, and, whenever a combination of favorable conditions occurs, they may be larger than any we have yet seen.

Second—In case these floods are not lessened by the construction of reservoirs, it is evident that a waterway must be maintained of sufficient size and grade to care for them within the banks of the channel. Other things being equal, the smoother the sides and bottom, the straighter the channel and the greater the fall, the more water is carried by a conduit of a given size.

Third—Increased waterway may be obtained either by deepening or broadening the channel, or by removing obstructions, raising the bridges, and prohibiting its use as a dumping-ground.

Fourth—If it be finally determined that the diversion of Cherry Creek is the most advantageous, it is proper to call attention to the fact that the present channel could not be entirely dispensed with, because of the great volume of water entering and originating below the point of diversion.

Fifth—To form final judgment on the best and most effective means of preventing future damage requires information and data which can be had only by actual surveys, and estimates based thereon. The importance of the interests involved and of the possibilities of damage justifies a thorough study of conditions, and we recommend that, before action is taken or a definite plan adopted, all obtainable information and data be submitted to, and passed on by, a competent board of engineers.

Respectfully submitted,

F. L. BARTLETT.
D. W. BRUNTON.
L. G. CARPENTER.

SUITS FILED AGAINST CITY BASED ON CHERRY CREEK FLOOD

The following information is obtained from the City Attorney's office:

The following suits claiming damages on account of the Cherry Creek flood of July 14, 1912, were filed in the District Court:

Case		
No. 54779	—J. K. Mullen, C. A. Bowman, George A. Nash, W. E. Warneke, and Robert S. Willoughby vs. City and County of Denver, to recover	$222,337.32
No. 54733	—Merchants Biscuit Company vs. City and County of Denver, to recover	14,910.04
No. 54767	—Henrietta E. Beal vs. City and County of Denver, to recover	2,000.00
No. 55106	—Cement and Lime Products Co. vs. City and County of Denver, to recover	4,994.33
No. 54544	—C. F. Enroth vs. City and County of Denver, to recover	700.00
No. 54572	—P. S. Bell and Mary A. Bell vs. City and County of Denver, to recover	1,800.00
No. 55126	—James R. Dresser, Wallace Clow, Archie B. Clow vs. City and County of Denver, to recover	4,500.00
No. 55485	—W. A. Grainger, doing business as W. A. Grainger Mercantile Company vs. City and County of Denver, to recover	500.00
	G. A. Luxford vs. C. B. & Q. R. R. and City and County of Denver	29,127.42
	Total	$280,809.11

As the cases had been heard by His Honor, J. A. Perry, judge of the District Court, the City Attorney's office appears in behalf of the city.

The following opinion was rendered:

IN THE DISTRICT COURT

No. 54733

State of Colorado, City and County of Denver, ss.

The Merchants' Biscuit Company, Plaintiff,

vs.

The City and County of Denver, Defendant.

OPINION

This is an action for damages for injuries alleged to have been caused by a flood which occurred in this city on July 14, 1912.

Plaintiff alleges that the city is traversed by a stream known as Cherry Creek; that this creek is the natural drainage outlet of a large territory; that the water-shed of the creek is and, since the first white settlement of the city, has been known to be subject to frequent, sudden, and violent storms, and to immense downpours of water, known as cloudbursts; that during and after these downpours vast volumes of water are precipitated upon the water-shed and seek their outlet through the channel of the creek; that the history of the creek and of the water-shed, and the character of the circumjacent territory, are such as to have made it not only possible, but also probable, that there would occur a flood of the character of the flood causing the injury alleged in the complaint.

Plaintiff alleges further that, prior to the occurrence of this particular flood, the defendant had circumscribed and fixed the natural channel of the creek; had built bridges over, and erected cross-dams and dumped rubbish in, the channel; had permitted others to build bridges over, and to dump rubbish in, the creek, and had failed to keep the channel clear of the accumulation of rock, sand, and debris; that, by reason of the action and non-action of the defendant in the premises, the natural channel and carrying capacity of the creek were greatly reduced; that the defendant did the acts complained of carelessly, unskillfully, and negligently, and without regard to the character or extent of the water-shed, or to the suddenness and violence of the storms likely to occur therein, or to the immense downpours of water likely to be precipitated; and that, in doing the acts complained of, the defendant did not adequately provide for carrying away the waters likely to be precipitated on the water-shed.

Plaintiff alleges further that, on July 14, 1912, a great flood occurred, whose waters, because of the defendant's negligence, stated in the complaint, filled the narrowed channel of the creek, overflowed the banks of the creek, entered in and upon the plaintiff's premises, and injured its property.

The matter comes up on defendant's general and special demurrer.

Although not so expressly stated in the complaint, it is fairly inferrible that the work done by the defendant was in connection with some public improvement, and, as it has not been suggested that the defendant was without power to do this work, I assume that the doctrine of *ultra vires* does not apply.

Among other matters called to my attention during the argument were the rules of law applicable to drains and sewers and to surface water, and these matters ought to be disposed of *in limine.*

A city is not liable for having wholly failed to provide a storm or sanitary sewer, or for having failed to provide a sufficient storm or sanitary sewer; its liability in this respect does not attach until after the sewer has been constructed, and then only upon proof of negligence in the manner of its construction or negligence in failing to keep it in repair.

A city is not liable for having failed to take care of what is known as surface water, or even for having actually caused surface water to drain off of its streets or other property and upon the property of an abutting lot-owner. Surface water is, in the words of an eminent English judge, a public enemy of whom everyone is at liberty to rid himself. Therefore, a city may grade its streets so as to drain the surface water upon an abutting lot, and the owner of such lot may raise it so as to drain the surface water into the street or upon the lot of his neighbor, and no liability will attach to anyone.

Surface water is the water precipitated on the general surface of land in the form of rain and snow.

The rules which define and state the limits of a city's liability in the matter of sewers and drains have no application, and the rules which exempt a city from liability in the matter of surface water must be carefully distinguished from the rules which apply where, as in this case, the city attempts to interfere with the flow of water in a natural stream or water-course.

If the inevitable consequence of this interfering is injury to private property, as where the water is diverted from its natural course and caused to flow upon the property, the wisdom or utility of the public work necessitating its diversion, and the skill and care with which the work is done, are wholly immaterial; the city is liable in any event, for this would be an actual trespass, or rather an appropriation of private property for a public use, without compensation to the owner.

When, however, the interference with the natural flow of the water is not necessarily and inevitably injurious, as in this case, where the city has not diverted the water, but has attempted to straighten or improve the channel of the water-course, no liability will attach unless the city is shown to have been guilty of some negligence.

While a city may interfere with the flow of water in a natural stream or water-course, where the making of improvements or the doing of other public work requires such interference, still it must leave a channel which is adequate to carry off not only the water usually flowing through the stream and the annual freshets, but also the waters of floods similar to floods which have previously occurred with such frequency as to advise the officers and agents of the city, as reasonably prudent men, that they are likely to occur again.

The city is not to be considered an insurer, it is not to be charged with prophetic vision, and it cannot be held responsible for an extraordinary flood which it could not have foreseen, and the fact that previously as great a flood as, or a greater flood than, the one causing the injury may have occurred in the same stream will not of itself make the flood causing the injury an ordinary flood against which the city will be held to have been bound to provide.

I am aware of the fact that in Mayor etc. of New York vs. Bailey, 2 Den., 435, it is stated that a city will be liable if a flood similar to the one causing the injury has occurred within the memory of man, but that statement is contrary to the rule laid down by the weight of the authorities.

According to the complaint, the flood which injured the plaintiff was not extraordinary, but was a flood which should have been anticipated and foreseen.

The plaintiff does not charge specifically that the defendant knew or, by reasonable investigation, could have ascertained that this flood was likely to occur. All that is charged is that the matters showing the possibility and probability of the occurrence of the flood were generally known. This is a matter of evidence, from which knowledge on the part of the defendant may be inferred, but it is not the pleading of the ultimate fact of knowledge.

Plaintiff's allegations of negligence are too general. It is nowhere specifically charged that the defendant has failed to use ordinary care and prudence in adopting the plan of the public work which it undertook to perform, or in carrying that plan into effect.

Plaintiff has not stated where its property is located with reference to the new channel, and its allegation that its property was injured by narrowing of the channel and consequent overflow of the stream is a legal conclusion.

It does not necessarily follow that, because the channel has been narrowed and the water has overflowed the banks of the stream, the injury which the plaintiff may have sustained was due to those causes.

In all of the cases cited by counsel the properties injured were alongside the stream; in the cases where the channel had not been diverted the injury was caused by back-water; and in the cases where the channel was diverted the injury was caused by the water overflowing the banks of the new channel, and thus reaching land which would have been uninjured except for the change of the channel.

The location of plaintiff's property should have been shown; if it then appeared that it was above the upper end of the new channel, or that it was alongside of the new channel, an injury from the backing of the water would have been made out.

If it had appeared from the complaint that the property of the plaintiff was below the lower end of the channel and within the natural flood water-course of the stream, defendant's acts would not necessarily have injured the plaintiff.

The effect of narrowing the channel and thereby causing an overflow would be to retard the water and cause a great portion of it to spread and never reach the property of the plaintiff, and in the case last supposed, when the flood reached and passed the plaintiff's property, instead of being increased, it would have been diminished in quantity and velocity, and any damage sustained by the plaintiff would have been from water which had overflowed the new channel or been obstructed by the bridges above the plaintiff's property, and the manner of the injury ought to be shown.

The defendant has called my attention to the distinction which the law makes in regard to the judicial and ministerial acts of a city. While the law does make this distinction, and

hold that a city is not liable for a judicial act, it gives no general rule whereby a judicial act can be distinguished from a ministerial act, but determines the question upon the facts of each case as they arise. I do not believe that this rule can be invoked where it is charged that the city was negligent in adopting or in carrying out a plan of public improvement, and the cases cited on this argument assume that the rule does not apply in cases where a city has interfered with a natural stream or water-course.

As the plaintiff has not shown that it was incumbent upon the defendant to keep the water-course clear, the defendant is not liable for its mere non-action in failing to remove the accumulation of sand, rock, and debris, or in failing to prevent the dumping of rubbish, or in failing to prevent the building of railroad bridges, in the channel. It would have been liable if it appeared from the complaint that the defendant had actually made the stream a public dumping-ground, or actually licensed the building of these railroad bridges, and that the plaintiff had been injured in consequence.

I am of the opinion that the defendant's general demurrer should be sustained, for the following reasons, viz.:

(1) The complaint does not state that the defendant knew, or that by reasonable investigation it could have ascertained, that the flood in question, or a similar flood, was likely to occur.

(2) The complaint does not state that, in adopting or constructing the new channel, the defendant failed to use the ordinary care required to make the new channel of a size and capacity sufficient to carry off the water of such floods as were likely to occur.

(3) The complaint does not show how the injury which the plaintiff claims to have sustained was caused by the narrowing, changing, or obstructing of the channel, or how said injury was caused by anything the defendant is charged with having done or omitted.

For the above reasons the demurrer will be sustained.

By the court:

J. A. PERRY,
Judge.

METHODS OF FLOOD RELIEF IN FOREIGN COUNTRIES

(Appendix No. 5 of 1911 Report of Flood Commission of Pittsburg, Pa.)

With a few exceptions, all communities situated on low ground bordering rivers have suffered to a greater or less extent from inundation and have had to face the problem of flood relief. European cities and towns, as compared with the phenomenal development in America, have had a gradual growth that has extended over centuries instead of decades, and has given opportunity for a better and more complete solution of this problem; and it is quite natural that, in Europe, the construction of flood-relief works should be further advanced than in this country. It is to be expected, moreover, that countries that have given such thorough and successful attention to the development of their natural inland waterways for navigation should have made notable progress in river regulation.

As a rule, the methods of flood relief employed in foreign countries have, until comparatively recent years, been some form of local protection, as walls or dikes, filling in of low ground, straightening, deepening, and widening of river channels, etc. The works on the Danube, at Vienna and Budapest, are notable examples of these methods of flood relief. In certain cases, where the conditions were favorable, diversion channels have been built to accommodate the discharge in excess of the carrying capacity of the natural channel. This method has been recommended by the Flood Commission of Paris in its recent report, the studies having shown that by the construction of a diversion channel about 20 miles long, taking part of the flood flow of the Marne to the north around the city, and emptying into the Seine below the city, at Epinay, a reduction of 5.7 feet in a flood similar to that of 1910 could be obtained at a cost of $34,000,000. Local treatment of the flood problem by one or another of the above methods has been so widely followed, and, in each case, is so entirely governed by the local conditions, that it would seem useless and of little interest to give space in this discussion to the numerous examples of flood protection.

In comparatively recent years, however, another method of flood relief has been successfully employed in European countries—that of flood prevention by storage reservoirs. This is of such peculiar interest in connection with the report of this commission, which so largely deals with a solution of the Pittsburg flood problem by means of reservoir control, that the success of such works in other countries has been treated at length in the following pages, in order to show that, despite the doubts of the feasibility of this method which have been expressed, reservoirs for impounding and controlling damaging flood waters have been built and are being successfully operated.

RUSSIA

The greatest system of artificial reservoirs in Europe is located at the headwaters of the Volga and Msta rivers in Russia. The Volga, the greatest river in Europe, rises about 200 miles southeast of St. Petersburg, and flows eastwardly for about half its length of 2,325 miles, and then southwardly into the Caspian Sea. The Msta rises near the same point, but flows in a general northerly direction into the Baltic Sea.

The two river systems have for a long time been connected by artificial waterways, but navigation was not possible, except during high water, until advantage was taken of the natural reservoir sites afforded by the numerous lakes near the sources of the two rivers, which were converted into enormous storage reservoirs by the construction of low dams across their outlets. The combined capacity of the system is about 35,000,000,000 cubic feet, the largest reservoir having a capacity of 14,000,000,000 cubic feet. This system of reservoirs has been notably successful in preventing floods and in improving the navigation on the two rivers, the benefit to the latter being felt on the Volga for a distance of over 450 miles, and both rivers being navigable for three months longer than formerly.

GERMANY

The construction of storage reservoirs as a means of flood control has probably been more extensively carried on in Germany than in any other country. A number of these reservoirs are intended solely for purposes of flood control, while others are, in addition, used for navigation, power development, and water supply.

Wupper River.—The Wupper River drains about 240 square miles and empties into the Rhine on the east bank at Rheindorf. Before the construction of the dams, the river, on account of its steep slope and deforested, mountainous drainage basin, had a very irregular discharge. In long periods of drought it dropped as low as 0.05 second-foot per square mile, while in high water it often rose to 90 second-feet per square mile. The cities of Barmen and Elberfeld are on its banks and were often inundated, while the numerous water-power plants along the stream suffered very greatly from the low water. After long deliberation, the Wupper Dam Association was formed, for the control and improvement of the river, and this association has built the following two dams for the regulation of the flow.

Bever Valley Dam.—The Bever enters the Wupper in its upper course, near Huckeswagen. The dam on this stream, built in 1898, controls a drainage area of about 9 square miles and creates a reservoir of 116,500,000 cubic feet capacity, of which about 18,000,000 cubic feet are kept empty during the flood season. The dam is 52.5 feet high and was built at a cost of $343,200, or $2,950 per million cubic feet of storage.

Lingese Valley Dam.—This stream enters the Wupper near its headwaters, not far from Marienheide. In 1900 a dam was built in its valley, storing the run-off from about 4 square miles. The capacity of the reservoir is 92,000,000 cubic feet, of which 3,500,000 cubic feet are reserved for the storage of flood water. The dam is 61 feet high and cost $256,800, or $2,800 per million cubic feet of storage.

These dams, which have given excellent results, are supplemented in their control of floods by the storage in six other reservoirs, built for domestic and industrial supply, varying in capacity from 10,600,000 cubic feet to 211,800,000 cubic feet, and in cost from $1,930 to $8,670 per million cubic feet of storage. Another dam is now under construction, in the Kerspetal, a tributary in the upper basin of the Wupper. The reservoir has a catchment area of 10.6 square miles and a capacity of 564,800,000 cubic feet. The total area of the Wupper basin controlled by these mine reservoirs is 37 square miles, or 15 per cent. The total capacity of the nine projects is 1,242,560,000 cubic feet.

Ruhr River.—The Ruhr is the next tributary of the Rhine north of the Wupper, entering the Rhine from the east a short distance below Dusseldorf. It flows through the great iron and steel center of Germany, around Essen, Steele, and Mulheim, and the main river and its tributaries are extensively used as a source of domestic and industrial water supply.

There are twelve reservoirs on the tributaries of the Ruhr, built at various times between 1894 and 1910. These reservoirs control an aggregate drainage area of 71 square miles and have a combined storage capacity of 1,447,300,000 cubic feet, the individual capacities varying from 17,650,000 cubic feet to 353,000,000 cubic feet. The total cost of the work was $3,480,720, the cost per million cubic feet in the various projects varying from $1,765 to $4,400. The dams are of masonry, arched up-stream, and vary in height from 64 to 114 feet. The flood water stored in these reservoirs is used directly for domestic and industrial supply, and, in some cases, also for power development. The reservoirs were constructed for the additional purpose of improving the low-water flow of the Ruhr for domestic and industrial supply and for power purposes.

Rur River.—The Rur River enters the Rhine from the south, near Dusseldorf. On one of its principal tributaries, the Urft River, is located the highest and one of the most notable dams in Europe, built in 1901-1904, for the purpose of flood storage and water-power development. The water is conducted through a tunnel 9,200 feet long to the power station on the Rur River north of the reservoir, where it drops 360 feet and develops an average of 4,800 horsepower and a maximum of 12,000 horsepower.

The drainage area above the dam is 145 square miles, of which 53 per cent is wooded. The maximum discharge of the Urft River is about 20 second-feet, the minimum about 0.18 second-

foot, and the average about 1.46 second-feet per square mile of drainage area.

The dam contains 185,650 cubic yards of masonry, and is curved in plan, with a radius of 656 feet and a crest length of 741 feet. The maximum height is 190 feet, the thickness at the base 166 feet and at the top 18 feet. On the up-stream face of the dam an earthen embankment is built to within 82 feet of the crest, sloping back to the reservoir bed with a 2 to 1 slope paved with rock. The reservoir has a capacity of 1,606,000,000 cubic feet, a surface area of 534 acres, a maximum depth of 172 feet, and an average depth of 69 feet. The cost of $1,000,000, or $620 per million cubic feet of storage, was borne by an association made up of the city of Aachen and surrounding communities. No assessment has been made on the interests benefited below.

During the great flood of February, 1909, the Urft reservoir effectively protected the entire Rur valley. At this time the discharge of the Rur at Heimbach was 8,825 second-feet—greater than ever before recorded; while the Urft, which empties into the Rur a few miles above Heimbach, reached an unusual height, with a discharge of about 3,530 second-feet. Had the flood flow of these two streams been combined, a great rise and much damage would have resulted; but the Urft reservoir impounded 706,000,000 cubic feet without taxing the capacity, and the calamity was avoided.

Neckar River.—The Neckar River rises in the southern part of Wurttemberg, in southwestern Germany, and flows in a general northerly direction, emptying into the Rhine at Mannheim. It has a total length of 228 miles and a drainage area of 8,665 square miles.

The Department of the Interior of Wurttemberg has charge of all river work, including the maintenance of navigation and the prevention of floods. One-third the expense of such work is borne by the state, one-third by the municipalities, and one-third by the property-owners benefited. In very large and expensive undertakings the government pays one-half the cost.

A number of small reservoirs have been built for storing flood water, the largest of which has a capacity of about 22,000,000 cubic feet. Some of these reservoirs are emptied after each flood, while others are kept partly full, a certain amount of capacity being reserved for storage of flood water.

Weiseritz River.—The Weiseritz River rises in the mountains south of Dresden and flows northwardly for about 50 miles, emptying into the Elbe just below the city. It drains about 148 square miles, 37 per cent of which is forest-covered, and has a maximum discharge of 10,200 second-feet, or 69 second-feet per square mile, and a minimum of 1.4 second-feet, or about 0.01 second-foot per square mile.

In a single flood in 1897 the losses along this stream amounted to over $2,000,000. Immediately after this flood, $1,-

250,000 was spent for flood-protection work, and since then further measures of flood relief have been taken, including the construction of seven reservoirs. The two largest of these reservoirs are now completed—one at Malter, on the Red Weiseritz, and the other at Klingenberg, on the Wild Weiseritz. The Malter reservoir has a collection area of 40 square miles and a capacity of 308,875,000 cubic feet. The dam is 115 feet high, 630 feet long, 18 feet wide on top and 98 feet wide at the base. The entire cost, including land damages and relocation of railroad, highways, etc., amounted to $883,000, or about $2,860 per million cubic feet of storage. The Klingenberg reservoir controls a drainage area of 35 square miles and has a capacity of 536,150,000 cubic feet. The dam is 128 feet high, 1,017 feet long, 18 feet wide on top and 113 feet wide at the base. The total cost was $858,000, or $1,600 per million cubic feet. The water supply for a suburb of Dresden is taken from this reservoir.

These reservoirs reduce the maximum flow from 10,200 second-feet to 6,000 second-feet, which can be carried by the channel without overflow. The impounded water is released during low water and raises the minimum discharge from 1.4 second-feet to 70 second-feet.

Weser River.—The greatest artificial reservoir in Europe, except those in Russia at the headwaters of the Volga and Msta Rivers, is now under construction near Hemfurt on the Eder River, a tributary of the Weser, and will be completed in 1913. The reservoir is intended for the storage of the winter and spring flood water, for the feeding of the Rhine-Weser Canal, and for the raising of the low-water stage of the Weser in summer and autumn. This increase in low-water stage of the Weser will be about 1.2 feet at Hann Munden, 50 miles below the dam, and 0.5 foot at Minden, 124 miles further down-stream. From 3,000 to 5,000 horsepower will be developed at the dam.

The drainage area tributary to the reservoir is 552 square miles, the discharge from which at the dam site varies between 0.05 second-foot and 58 second-feet per square mile. The reservoir has a capacity of 7,144,720,000 cubic feet, a surface area of 2,964 acres, a length of 15.5 miles, and a maximum depth of 126 feet. The dam contains 392,222 cubic yards of masonry, quarried in the neighborhood, and is curved up-stream with a radius of 1,640 feet and a crest length of 1,345 feet. The maximum height above the bed of the valley is 136 feet, the width on top is 20.5 feet and on the bottom 110 feet. The project will cost $4,500,000, or $630 per million cubic feet of storage. Two-thirds of this money is appropriated by the Prussian Landtag and one-third by the city of Bremen, which is located at the mouth of the Weser.

The construction of another large reservoir on the Weser basin is planned, but not yet begun, on the Diemal, near Helminghausen.

Oder River.—The Oder River rises in the mountains in the north of Bohemia and flows in a northwesterly direction through

Prussia, emptying into the Baltic Sea a short distance below the city of Stettin. The river passes only about 50 miles to the east of Berlin, and as it is connected by canals with that city and thence with the Elbe River, and is navigable for nearly its entire length, it is an important stream commercially. The head of navigation is at Cosel, in the southern part of the province of Silesia, and from here down-stream to Breslau, the capital of the province, a distance of about 90 miles, the river is slackwatered.

Reservoirs for Flood Control and Navigation Purposes: Below Breslau the low-water stage gives about 3.9 feet depth, 0.7 foot less than the required depth for navigation. This lack of depth continues, gradually diminishing, to a point about 120 miles below, where the necessary depth of 4.6 feet becomes available. The extension of the system of locks and dams through this stretch was at one time considered, but it has finally been decided to obtain the additional depth by the construction of two large reservoirs on tributaries of the Oder above Breslau, which will perform the double purpose of controlling floods and of increasing the low-water stage by release of the water thus impounded. The required increase of 0.7 foot in the stage can be obtained by an additional flow of about 700 second-feet. The plans for these reservoirs are now completed, but work is not as yet begun. They will be built under the direction and at the expense of the Prussian government.

The larger of the two reservoirs is on the Glatzer Neisse, one of the principal upper tributaries of the Oder, entering on the left bank about 40 miles above Breslau. The drainage area above the dam is 906 square miles, mostly mountainous and hilly country, about 30 per cent of which is wooded. The annual rainfall varies between 25 and 32 inches, and the stream at the dam site has a maximum discharge of 42,360 second-feet, a minimum of 141 second-feet, and an average of 3,177 second-feet.

The dam, as proposed, is of earth, 37 feet high, 16,400 feet long, and 26 feet wide on top, with 3 to 1 slopes on both sides, the up-stream slope being faced with a layer of gravel about a foot thick. The reservoir has a maximum capacity of 3,600,600,000 cubic feet, 635,400,000 cubic feet of which are reserved for flood control. About 1,500 horsepower will be developed at the dam, while numerous small mills below will benefit by the improved flow and are to be assessed accordingly. The work will take from five to six years, and will cost $3,840,000, or about $1,070 per million cubic feet of storage.

The other reservoir is on the Malapane, a tributary entering the Oder from the east, about 50 miles above Breslau. The drainage area above the dam is 403 square miles, 50 per cent of which is in forest. The mean annual rainfall is about 28 inches, and the stream at the dam site has a maximum discharge of 10,590 second-feet, a minimum of 88 second-feet, and an average of 282 second-feet.

The cross-section of the dam is similar to that of the Glatzer Neisse dam, with a maximum height of 33 feet and a crest length of 15,420 feet. The maximum capacity of the reservoir is 3,124,-050,000 cubic feet, 370,650,000 cubic feet of which are reserved for flood control. It is planned to develop about 750 horsepower at the dam, and to obtain some revenue from assessments upon the numerous water-power interests benefited by the increased low-water flow. The project will cost about $2,880,000, or $900 per million cubic feet of storage, and it is estimated that it will take five years to build.

The flood control effected by these reservoirs is intended as a means of relief additional to extensive channel improvements and dikes which are planned and already partly carried out, as a result of the serious flood damages which have been experienced along the valley of the Oder, particularly at the city of Breslau.

The Oder Improvement Bureau of the Prussian government examined in all about 150 locations for reservoirs to increase the low-water flow of the Oder for navigation purposes. Ten sites, in addition to the two described above, were selected, and preliminary plans and estimates were made; but it has not as yet been definitely decided to build any of these reservoirs, except the two large projects mentioned, for which final plans and estimates are completed. The capacities and costs of the ten projects upon which preliminary estimates were made are as follows:

(1) Lazisk Reservoir. On a tributary of the Olsa River, which enters the Oder on the right, about 115 miles above Breslau. Capacity, 618,300,000 cubic feet. Cost, $840,000, or $1,360 per million cubic feet of storage.

(2) Schwesterwitz Reservoir. On the Straduna River, which enters the Oder on the left, about 80 miles above Breslau. Capacity, 169,560,000 cubic feet. Cost, $833,000, or $4,900 per million cubic feet of storage.

(3) Lobkowitz Reservoir. On the Hotzenplotz, which enters the Oder on the left, about 70 miles above Breslau. Capacity, 324,000,000 cubic feet. Cost, $1,309,000, or $4,000 per million cubic feet of storage.

(4) Krappitz Reservoir. Also on the Hotzenplotz River. Capacity, 270,000,000 cubic feet. Cost, $785,000, or $2,900 per million cubic feet of storage.

(5) Dembiohammer Reservoir. On a tributary of the Malapane River. Capacity, 704,700,000 cubic feet. Cost, $1,561,000, or $2,220 per million cubic feet of storage.

(6) Schulenburg Reservoir. On a tributary of the Malapane River. Capacity, 475,200,000 cubic feet. Cost, $968,000, or $2,030 per million cubic feet of storage.

(7) Waltdorf Reservoir. On a tributary of the Glatzer Neisse. Capacity, 108,270,000 cubic feet. Cost, $607,000, or $5,600 per million cubic feet of storage.

(8) Hunern Reservoir. On the Hunernbach, a small tributary emptying into the Oder on the left bank, about 22 miles above Breslau. Capacity, 247,050,000 cubic feet. Cost, $642,000, or $2,600 per million cubic feet of storage.

(9) Allstadt Reservoir. On the Weide River, which empties into the Oder from the right, about 6 miles below Breslau. Capacity, 247,050,000 cubic feet. Cost, $1,428,000, or about $5,800 per million cubic feet of storage.

(10) Raaben Reservoir. On a tributary of the Weistritz River, which empties into the Oder on the left bank, about 6 miles below Breslau. Capacity, 391,500,000 cubic feet. Cost, $1,119,000, or $2,860 per million cubic feet of storage.

Reservoirs for Flood Control and Power Purposes: Extensive investigations of the feasibility of constructing storage reservoirs for the prevention of the damaging floods in the valley of the Oder and its tributaries in Silesia were carried on under the direction of the Prussian minister of commerce and trade in 1895-1898. Many possible locations for reservoirs were found, and a number that were very favorable. These reservoirs were to be primarily for flood prevention and secondarily for industrial uses.

The act of July 3, 1900, granted about $9,300,000 for the construction of flood-control reservoirs on certain dangerous tributaries on the left of the Oder. The surveys and investigations were then continued by the province of Silesia and a number of additional favorable sites studied. Up to the middle of 1911, sixteen projects had been adopted, and of these seven reservoirs had been completed, six more were under construction, and plans and estimates for three more were ready. The reservoirs, with the exception of the Marklissa and Mauer projects, which are also used to develop power, are constructed simply for flood prevention, and are usually kept empty and ready to store flood water.

In all, thirty-eight favorable locations were found, and for the twenty-two in addition to the sixteen mentioned above the cost of construction has been tentatively estimated, but they have not as yet been adopted. Twelve of these twenty-two projects would be used for power development, as well as for flood control.

The thirteen reservoirs which have been completed or are now under construction are described below:

(1) Arnoldsdorf Reservoir. This reservoir is located near Arnoldsdorf, on the Goldbach, a tributary of the Hotzenplotz, which enters the Oder on the left bank about 70 miles above Breslau. The dam is of earth, and the reservoir will have a capacity of 79,380,000 cubic feet. The work was begun in 1906 and is not yet completed. The cost of the project will be $119,000, or about $1,500 per million cubic feet of storage.

(2) Woelfel Reservoir. This reservoir was built in 1905-1908 on the Woelfelsbach, an upper tributary of the Glatzer Neisse. It has a capacity of 32,130,000 cubic feet and controls a drainage

area of about 10 square miles. The dam is of masonry, arched upstream, with a radius of 820 feet, and is 98 feet high, 10 feet wide on top, 62 feet wide at the base, and 361 feet long. The total cost of the work was $124,000, or $3,860 per million cubic feet of storage.

(3) Seitenberg Reservoir. The Seitenberg Reservoir is located near the village of that name, on a tributary near the headwaters of the Glatzer Neisse, which enters the Oder on the left bank, about 40 miles above Breslau. The dam is of earth, and the reservoir has a capacity of 40,500,000 cubic feet. The work was carried out in 1905-1908, at a cost of $68,000, or $1,680 per million cubic feet of storage.

(4) Schonau Reservoir. This reservoir is located on the Steinbach, a small tributary of the Katzbach, which enters the Oder on the left bank, 33 miles below Breslau. The work was begun in 1907 and is still under way. The dam is of earth, and the reservoir will have a capacity of 56,430,000 cubic feet. The estimated cost of the project is $90,000, or $1,600 per million cubic feet of storage.

(5) Klein-Waltersdorf Reservoir. This reservoir was begun in 1909, on a tributary near the headwaters of the Katzbach, and is not yet completed. It has an earthen dam, and will have a capacity of 16,930,000 cubic feet. The project will cost $40,000, or $2,360 per million cubic feet of storage.

(6) Buchwald Reservoir. This reservoir is located near Buchwald, not far from the headwaters of the Bober, the drainage area above the dam being only 23 square miles. The dam is of masonry, and is 48 feet high and 722 feet long. The reservoir has a capacity of 77,660,000 cubic feet, and was built in 1903-1906, at a total cost of $262,000, or about $3,400 per million cubic feet of storage.

(7) Grussau Reservoir. The Grussau Reservoir is located on an upper tributary of the Bober, about 6 miles above Landeshut. The dam is of earth, and the reservoir has a capacity of 28,080,000 cubic feet. The project was built in 1903-1906, at a cost of $86,000, or $3,060 per million cubic feet of storage.

(8) Zillerthal Reservoir. This reservoir was begun in 1909, on an upper tributary of the Bober, and is not yet completed. It has an earthen dam, and will have a capacity of 105,840,000 cubic feet. The total cost will be $274,000, or about $2,600 per million cubic feet of storage.

(9) Herischdorf Reservoir. This reservoir is located on the Heiderwasser, a tributary of the Bober, near Herischdorf. It has a capacity of 141,200,000 cubic feet and controls a drainage area of about 36 square miles. The dam is of earth, with a maximum height of 27.5 feet and a crest length of 4,920 feet. It was built in 1903-1906, at a total cost of $219,000, or $1,550 per million cubic feet of storage.

(10) Warmbrunn Reservoir. This reservoir was built in 1906-1908, on an upper tributary of the Bober. The dam is of earth, 23 feet high and 9,840 feet long, and the reservoir has a capacity of 211,950,000 cubic feet and a catchment area of 46 square miles. The total cost of the project was $381,000, or $1,800 per million cubic feet of storage.

(11) Mauer Reservoir. The largest reservoir on the Bober, near Mauer, was begun in 1905 and is now nearly completed. It has a capacity of 1,765,000,000 cubic feet and controls a drainage area of 467 square miles. The dam is built of masonry, arched up-stream, and when completed will be 196 feet high, or 6 feet higher than the Urft Dam. The total cost of the work will be about $1,785,000, or about $1,010 per million cubic feet of storage. About 60 per cent of the capacity will be reserved for flood control and the remainder used for power development.

(12) Friedelberg Reservoir. This reservoir is located on a tributary of the Queiss, about 11 miles above the Marklissa Reservoir, and controls a drainage area of about 24 square miles. It was begun in 1908 and is not yet completed. The earthen dam is 37 feet high and 1,968 feet long, and the reservoir will have a capacity of 120,150,000 cubic feet. The estimated cost is $119,000, or $990 per million cubic feet of storage.

(13) Marklissa Reservoir. The Marklissa Reservoir is located on the Queiss River, a few miles above Marklissa. The stream rises in the mountains of southern Silesia and flows northwardly into the Bober River, which empties into the Oder at Crossen. The Queiss flows parallel to and about 20 miles to the east of the Gorlitzer Neisse, and in topography, rainfall, and runoff is very similar to that stream, the same heavy rainfalls having repeatedly caused destructive floods on both streams.

The drainage area above the dam is 118 square miles, and the reservoir has a capacity of 529,500,000 cubic feet and a surface area of 346 acres. The dam, which is of masonry, arched up-stream, is 141 feet high, 27 feet wide on top, 124 feet wide at the base, and 426 feet long. It was built in 1901-1904 by the province of Silesia, at a cost, including land, damages, etc., of $750,000, or $1,418 per million cubic feet of storage.

The design of this reservoir is based upon a careful study of the flood of 1897, the greatest ever experienced on the Queiss River. The channel of the Queiss at Marklissa will carry 3,880 second-feet without overflow, and during the flood of 1897 the discharge rose to 27,530 second-feet, or about 230 second-feet per square mile. The discharging apparatus at the dam is so arranged that 3,880 second-feet can be released during the filling of the reservoir. At the level where the capacity of 529,500,000 cubic feet is reached, which is 6.5 feet below the crest of the dam, there are two spillways, one on each side of the valley, with a total crest length of 223 feet. When the water reaches this level and begins

to flow over the crests of these spillways, the gates are gradually closed as the water rises, so as to keep the discharge at 3,880 second-feet. As a head of 3 feet on the spillways is necessary to give the allowable discharge of 3,880 second-feet, the additional capacity of 42,360,000 cubic feet, due to this added depth, can be regarded as a protection against floods, bringing the total capacity of the reservoir for flood protection up to 571,860,000 cubic feet.

The reservoir is arranged so that 176,500,000 cubic feet are kept filled, but, on the approach of the flood, can be released in time to make the full capacity of the reservoir available for flood control. This water is used for the development of power, at a power station located a few hundred feet below the dam, where about 1,000 horsepower is developed during the four driest months, and 2,400 horsepower during the other eight months of the year. The release of this water during the low-water season increases the flow of the Queiss to about 140 second-feet, or about four times its former minimum, which is of great benefit to the numerous mills on the stream below the dam.

The following are the three reservoirs for which plans and estimates are prepared:

(1) Kaufung Reservoir. On the Katzbach, near the headwaters. Capacity, 24,003,000 cubic feet. Cost $63,000, or $2,630 per million cubic feet of storage.

(2) Grabel Reservoir. On a tributary of the Katzbach. Capacity, 31,590,000 cubic feet. Cost $71,000, or $2,250 per million cubic feet of storage.

(3) Alt-Weissbach Reservoir. On a tributary of the Bober. Capacity, 18,522,000 cubic feet. Cost $59,000, or $3,180 per million cubic feet of storage.

AUSTRIA

In Austria the most important work of flood control by means of storage reservoirs is that on tributaries of the Oder and Elbe Rivers in Bohemia.

Oder River.—One of the most notable groups of reservoirs built for flood control in Europe is composed of six projects on the Gorlitzer Neisse, near Reichenberg, in Bohemia. This stream rises in northern Bohemia and flows northwardly for 124 miles, emptying into the Oder River about 15 miles below Crossen in Prussia. Its valley receives a heavy precipitation in its upper portion, 13.5 inches in 24 hours having been recorded at some points, and has been repeatedly devastated by floods; so that, after the great flood of 1888, an association was formed to plan and carry out the construction of protection and regulation works, consisting of widening and straightening the channel, and raising and protecting the banks. The estimated cost of these improvements was so heavy, and their probable effectiveness in a great flood so doubtful, however, that practically nothing was done by the association, the actual work confining itself to the repairing of damages and

the building of the bank protections most urgently needed by the individual property-owners.

In July, 1897, this part of Europe was again visited by devastating floods, which so revived public interest in flood relief that a convention, in which all the neighboring cities and towns were represented, was held in Reichenberg in the fall of that year. At this meeting it was decided to investigate the feasibility of constructing reservoirs for flood control. In January, 1901, the preliminary studies were sufficiently complete to establish the general plans, which contemplated the construction of six reservoirs in the neighborhood of Reichenberg, controlling the run-off from 29 square miles, and in critical flood time holding back about 3,530 second-feet of damaging flood discharge.

The result of the investigations gained the association many new supporters and assured the sympathy of the population of the entire valley of the Neisse with the project. In fact, one of the most noteworthy features of this undertaking is the widespread interest it aroused in the surrounding country and the universal financial support it received. Although all the reservoirs are located in Bohemia, the benefits both in flood control and increase of low-water flow are felt by the Saxon and Prussian interests along its lower course, and these two countries, together with various cities, communities, and private interests, co-operated with Bohemia in their construction. The total cost of the work was $1,320,000, and the following contributions show the extent of the co-operation:

Bohemian government	$660,000
Prussian government	38,400
Prussian province of Silesia	9,600
Prussian county of Ober-Lausitz	14,400
City of Gorlitz (Prussia)	14,400
Saxon government	24,000
Combination of Saxon and Prussian water interests	72,000

It is also of special interest that the users of water for power development from the Grunwald, Harzdorf, and Friedrichswald reservoirs pay $12 per horsepower, and from the other three reservoirs, $28 per horsepower per year. The total contribution to the low-water flow of the Neisse from the six reservoirs is about 34 second-feet.

The main features of the six reservoirs are as follows:

Harzdorf Reservoir. This reservoir controls the run-off from 6 square miles, and has a maximum capacity of 22,239,000 cubic feet, 8,119,000 cubic feet of which are reserved for flood control. The dam is of masonry, arched up-stream with a radius of 394 feet, and is 62 feet high, 15 feet wide on top, 53 feet wide at the base, and 515 feet long, containing in all 20,918 cubic yards of masonry. On the up-stream side, as in the Urft Dam, an earthen embankment rises to about two-thirds the height of the dam, sloping back to the stream-bed with a 3 to 1 paved slope. The work was carried out in 1902-1904, at a cost of $119,000 for the

dam, and a total cost of $165,000, or $7,419 per million cubic feet of storage.

A short distance above slackwater of the reservoir there is a weir with an automatic self-registering gauge, which has an electric signal connecting with the house of the watchman at the dam, so that, when the inflow exceeds a certain prescribed amount, he is warned and can operate the gates and regulating apparatus accordingly.

Friedrichswald Reservoir. This reservoir has a catchment area of about 1.6 square miles and a maximum capacity of 70,600,000 cubic feet, 35,300,000 cubic feet of which are reserved for storage of flood water. The dam, which is of masonry, arched up-stream with a radius of 984 feet, is 92 feet high, 15 feet wide on top, 65 feet wide at the base, and 1,115 long. It contains 54,911 cubic yards of masonry, and was built in 1902-1906, at a cost of $320,000 for the dam proper, and total cost of $360,000, or $5,100 per million cubic feet of storage.

Voigtsbach Reservoir. The water-shed above this dam includes an area of 2.7 square miles, and the dam creates a storage of 8,825,000 cubic feet. The dam is of masonry, arched up-stream with a radius of 574 feet, and is 52 feet high, 15 feet wide on top, 35 feet wide at the base, and 538 feet long. It contains 15,690 cubic yards of masonry and was built in 1904-1906. The cost for the dam and appurtenances was $83,600, and the total cost was $94,400, or $10,700 per million cubic feet of storage.

Muhlscheibe Reservoir. This reservoir has a catchment area of 2.6 square miles and a capacity of 8,825,000 cubic feet. The dam is of masonry, arched up-stream with a radius of 656 feet, and is 72 feet high, 15 feet wide on top, 48 feet wide at the base, and 508 feet long. It contains 20,918 cubic yards of masonry, and was built in 1904-1906, at a cost of $123,000, or $14,000 per million cubic feet of storage.

Gorsbach Reservoir. This reservoir, which is not yet completed, controls a drainage area of 4.6 square miles and has a capacity of 17,650,000 cubic feet, 8,825,000 cubic feet of which are reserved for flood control. The dam is 70.5 feet high, 15 feet wide on top, 47 feet wide at the base, and 848 feet long, being arched up-stream with a radius of 738 feet. It contains 41,837 cubic yards of masonry, and its total cost, when completed, will be $206,000, or $11,670 per million cubic feet of storage.

Grunwald Reservoir. The drainage area above the dam is 10.3 square miles, 8.1 square miles of which are tributary to two other small streams, their flood run-off being conducted to this reservoir, which has a capacity of 95,310,000 cubic feet. The dam is of masonry, arched up-stream with a radius of 1,148 feet, and is 65.6 feet high, 15 feet wide on top, 49 feet wide at the base, and 1,378 feet long. It contains 56,218 cubic yards of masonry, and was built in 1906-1908, at a cost of $540,000, or $5,770 per million cubic feet of storage.

Elbe River.—The work of constructing storage reservoirs for flood control has been carried out on the Elbe River and tributaries in Bohemia since 1903 by a Commission for River Regulation. The work of this commission includes reforestation for the purpose of retarding the run-off and preventing erosion, about $145,000 having been expended for this purpose in 1906-1909. Sixty per cent of the cost of carrying out the work of the commission is appropriated by the Austrian government and 40 per cent by the Bohemian government. The following reservoirs are now being built:

Konigreiche-Walde Reservoir. This reservoir is located above Konighof, on the main river near its source in northern Bohemia, the drainage area above the dam being 200 square miles. It has a capacity of 320,887,000 cubic feet, of which 268,487,000 cubic feet are reserved for flood water. The dam is of masonry, arched up-stream, and is 136 feet high, 23.6 feet wide on top, 124 feet wide at the base, and 735 feet long. The total cost of the work will be $965,000, or about $3,000 per million cubic feet of storage.

Spindlemuhle Reservoir. This reservoir is also located on the main river, further up-stream than the Konigreiche-Walde Reservoir, and has a catchment area of 22.4 square miles. The capacity of the reservoir is 119,500,000 cubic feet, of which 106,000,000 cubic feet are reserved for flood storage. The dam is of masonry, arched up-stream, and is 136 feet high, 16.4 feet wide on top, 118 feet wide at the base, and 492 feet long. The spillway and discharging apparatus can accommodate 7,060 second-feet, or 316 second-feet per square mile of drainage area. The work, when completed, will cost $652,880, or $5,464 per million cubic feet of storage.

Elinsko Reservoir. This reservoir is located near the headwaters of the Chrudimka, a tributary of the Elbe, rising in eastern Bohemia and flowing northward into the Elbe at Pardubitz. The drainage area above the dam is 21.6 square miles, and the reservoir has a capacity of 81,190,000 cubic feet, 60,010,000 cubic feet of which are reserved for flood control. The dam is of earth, 40 feet high, 16.4 feet wide on top, and 656 feet long. It will cost, when completed, about $150,000, or $1,850 per million cubic feet of storage.

Parizov Reservoir. This reservoir is located on the Doubravka, the next important tributary of the Elbe west of the Chrudimka, entering the main river from the south, above Kolin. The reservoir has a catchment area of 80.7 square miles and a capacity of 60,010,000 cubic feet. The dam is of masonry, arched up-stream, and is 101 feet high, 14.8 feet wide on top, and 84.8 feet wide at the base. The total cost will be $299,686, or $5,000 per million cubic feet of storage.

In addition to the projects described above, the following reservoirs are proposed:

On the Aupa River. The Aupa rises in the extreme eastern part of Bohemia and flows westwardly into the Elbe at Konig-gratz. Its tributaries are subject to frequent sudden floods, during which extremely high rates of run-off are attained, and it is therefore an important contributor to high water in the Elbe. Three reservoirs are to be constructed on its tributaries.

(1) Below the junction of the Great and Little Aupa. The drainage area above the dam is 29.7 square miles, from which the maximum recorded discharge is 10,943 second-feet, or 370 second-feet per square mile. The reservoir will have a capacity of 123,550,000 cubic feet. It will cost $1,220,000, or $9,880 per million cubic feet of storage.

(2) On the Little Aupa. The reservoir will have a catchment area of 11.9 square miles and a capacity of 106,711,900 cubic feet, of which 88,250,000 cubic feet will be reserved for flood water. The dam will be of masonry, arched up-stream, and will be 157 feet high above the foundation, 19.7 feet wide on top, and 593 feet long. There will be a spillway 98 feet wide on top of the dam to accommodate the maximum flood discharge of 4,589 second-feet, or 385 second-feet per square mile of drainage area. It will cost $800,000, or $7,500 per million cubic feet of storage.

(3) Near Slatina. The drainage area above the proposed dam is 158.6 square miles, and the capacity of the reservoir will be 307,110,000 cubic feet. The dam will be of masonry, 115 feet high above the foundation, 23 feet wide on top, and 712 feet long. The spillway over the dam will accommodate the maximum discharge of 11,650 second-feet. The estimated cost is $850,000, or $2,770 per million cubic feet of storage.

On the Doubrava. The reservoir will have a catchment area of 37.3 square miles and a capacity of 48,000,000 cubic feet. The dam will be of earth, 37 feet high, 20 feet wide on top, and 703 feet long.

On the Kreibitzbache, near Kreibitz. The reservoir will have a catchment area of 24.7 square miles and a capacity of 31,770,000 cubic feet. The dam will be of earth, 77 feet high. The total cost will be $126,460, or $4,000 per million cubic feet of storage.

On the Sazawa, near Sechau. The drainage area above the proposed dam is 166 square miles, and the capacity will be about 400,000,000 cubic feet.

On the Boticbache, near Hostivau. The reservoir will have a capacity of 27,922,300 cubic feet and will cost $207,137, or $7,400 per million cubic feet of storage.

On the Iser. Two reservoirs are proposed on this stream together controlling a drainage area of 8.8 square miles, and having a combined capacity of 225,920,000 cubic feet, 76,543,000 cubic feet of which will be reserved for flood control. The total cost will be $458,000, or about $2,027 per million cubic feet of storage. These reservoirs are to be built by private enterprise

for water-power development, but the work will be aided by a contribution from the Commission for River Regulation on account of the above-mentioned capacity reserved by agreement for flood control.

Studies have also been completed for six other reservoirs for flood control on tributaries of the Elbe in Bohemia.

Wien River.—The Wien River is a small stream rising to the westward of the city of Vienna and flowing in a general easterly direction into the Danube at Vienna. It drains an area of about 86 square miles and has a very irregular flow, being subject to frequent sudden freshets, which in past years have caused great damage in Vienna, as the river flows directly through the city.

In the early nineties, studies for a method of relief from these floods were taken up by the Department of Public Works of Vienna, and plans were prepared for their control and for the improvement of the channel for some distance above its mouth. This work was carried out in the years 1895-1900 and consists of the walling-up of the channel from the mouth to Weidlingau, a distance of about 10.6 miles, and of the construction of seven small reservoirs near the head of this walled-in stretch, at the villages of Weidlingau and Hadersdorf.

The system of reservoir control is designed upon the basis of a possible maximum run-off of 330 second-feet per square mile of drainage area. The reservoirs stretch along the side of the valley for about a mile, and are separated from the river channel by a heavy concrete wall, and from each other by low concrete dams, forming a series of terraces, with about 6.5 feet difference in elevation between each water surface. They have a combined capacity of 56,480,000 cubic feet and are designed to hold back the flood flow in excess of the carrying capacity of the channel below Weidlingau. This is accomplished by means of an ingenious regulating device at the upper end of the works, which allows any desired amount of the flood flow to be diverted into the reservoirs. This flood water is only temporarily stored, being released as soon as the discharge has fallen sufficiently. The reservoir furthest up-stream serves as a settling basin for gravel, sand, and silt, and prevents this material from passing down the channel or into the lower reservoirs. The beds of the lower basins are used for raising grass, two crops of which are cut annually, while in winter the basins are flooded and the ice is harvested.

The total cost of the reservoirs was $1,680,000. Several floods have occurred since their completion, and they have served their purpose admirably.

FRANCE

The great floods of 1856 in France agitated the question of flood prevention by reservoir control. Elaborate studies were made on the Rhone, Garonne, and Loire Rivers, by order of

Emperor Napoleon III, and the findings of the French engineers are included in the following:

Rhone River.—The Rhone rises in eastern Switzerland and flows westwardly through Lake Geneva into France, where it is joined at Lyons by its principal tributary, the Saone, and flows southwardly for 205 miles into the Mediterranean. It has a total length of about 450 miles and a drainage area of about 36,700 square miles.

At a cost of $6,800,000, 7,500,000,000 cubic feet of storage could be created above Lyons, where the drainage area is about 20,500 square miles. The reduction of the 1856 flood that would have been effected thereby was estimated as 3.3 feet at Lyons, which would have gradually diminished downstream. Additional storage of about 11,000,000,000 cubic feet could have been created upon the Durance for about the same amount, but as this tributary enters the Rhone only about 60 miles from the sea, where the flood discharge is very considerable, the storage would have had relatively small effect in reducing the flood height on the main river, and this only for a short distance. The studies demonstrated, therefore, that a reduction of flood height could be obtained by reservoir control, but that, owing to the lack of suitable sites, sufficient storage could not be created to reduce floods below the stage where they would cause damage.

This investigation does much to prove the effectiveness of artificial storage. With only 7,500,000,000 cubic feet of storage, a reduction of 3.3 feet in flood height could have been obtained at a point in the river where the total drainage area is 20,500 square miles. Had suitable sites been available for the creation of, say, 25,000,000,000 cubic feet of reservoir capacity—a not unreasonable amount—a reduction of over 10 feet could doubtless have been obtained.

The consideration of the effect of the natural storage on the flow of the Rhone at Lyons is interesting and suggestive. The drainage area above the city is about the same as at Pittsburg, and both cities are located at the confluence of two large rivers. Both the Rhone and the Saone have extensive natural storage, and its effect is very noticeable in their discharge.

On the Rhone, 131 miles above Lyons, is Lake Geneva, with a surface area of 223 square miles, or about 8 per cent of the tributary drainage area of 2,663 square miles. One foot rise in the level of this lake represents a storage of 6,200,000,000 cubic feet. In the great flood of 1856 the Rhone discharged into Lake Geneva at the rate of 42,360 second-feet, or 21 second-feet per square mile. At this rate, for the entire drainage area, including the lake, the discharge below Geneva would have been 56,480 second-feet. It actually amounted to only 11,472 second-feet, or only 4.3 second-feet per square mile. The lake, therefore, acted as a natural reservoir, and its storage reduced the flow of the Rhone by about 45,000 second-feet.

On the Saone there is a very large natural storage, amounting to fully 50,000,000,000 cubic feet, due to the overflow of the bottom lands in its valley for a stretch of 100 miles above Lyons. As a result, the run-off of the Saone in the great flood of 1856 was only 4 second-feet per square mile.

Without these two natural storage reservoirs, the flow of the Rhone at Lyons would undoubtedly have been more than twice as great. The actual discharge amounted to less than 250,000 second-feet, or to but very little more than the flow at the 22-foot stage at Pittsburg. Had this natural storage been artificially created by means of a number of reservoirs, its effect would have been the same.

There is practically no natural storage on the Allegheny or Monongahela basins. The surveys of this commission, however, have shown that favorable sites exist for the creation of artificial storage to the amount of over 100,000,000,000 cubic feet, and the conditions on the Rhone at Lyons are an admirable illustration of the effect of such storage.

Garonne River.—The investigations on this river showed that, if artificial storage of about 33,000,000,000 cubic feet capacity could be created, the greatest floods could be kept within the river banks. The reservoir plan was rejected because of the difficulty of obtaining suitable sites, and because the cost of constructing reservoirs, $24,000,000, was considered excessive.

Loire River.—The French engineers recommended the project of controlling the Loire by storage reservoirs, but the work has never been carried out, as the estimated cost of about $13,000,000, though no greater than the flood damages at Pittsburg in the last ten years, was considered too great. The effectiveness of this method of flood control is demonstrated by the findings of the board of engineers.

The Loire River is formed by the junction of the Upper Loire and Allier Rivers at the city of Nevers. The former drains about 7,000 and the latter about 4,500 square miles. The conditions affecting run-off are very similar on the two streams, and their flood waves arrive at Nevers at practically the same time.

The investigations showed that about 8,250,000,000 cubic feet of storage could be created on the Upper Loire by the construction of twenty-two reservoirs, and about 10,000,000,000 cubic feet on the Allier by building sixty-three reservoirs. These reservoirs would reduce the maximum flow of the Upper Loire from 153,600 second-feet to 111,700 second-feet, and of the Allier from 167,700 second-feet to 104,700 second-feet; a total reduction of about 105,000 second-feet from a total flow of 321,000 second-feet, or over 30 per cent. This would reduce floods below the danger line for a distance of about 180 miles below the junction of the rivers, while above this point the effect would be much greater.

The Allegheny at Pittsburg and the Loire at Nevers are very similar in size of drainage area and in maximum flow. The studies of the French engineers have shown that, with a storage of 18,250,000,000 cubic feet on the Loire, the floods can absolutely be controlled and reduced below the danger line for a distance of 180 miles below the city of Nevers. The reservoirs proposed on the Allegheny basin have a combined capacity of about 50,000,000,000 cubic feet, or nearly three times the capacity of the storage that was proposed on the Loire.

Seine River.—The Flood Commission of Paris, appointed at the time of the disastrous floods of the Seine in February and March, 1910, issued its report during the summer of that year, and, with regard to reservoirs as a means of flood control, stated that this method is not applicable to the basin of the Seine. It could only be applied on two tributaries, the Upper Seine and the Aube, where 7,000,000,000 cubic feet of storage would have an appreciable effect on the floods in the Seine at Paris, but the construction of the necessary reservoirs would involve prohibitive land damage, as a rich farming country would be flooded.

Other Rivers.—There are three notable reservoirs for flood control in France. The Furens Dam was built by the French government in 1862 to protect the town of St. Etienne from the floods of the Furens River. It is a curved masonry dam, about 184 feet high and 326 feet long on the crest, and stores about 56,500,000 cubic feet. The cost was $318,000, or about $5,630 per million cubic feet of storage, 60 per cent of which was contributed by the town of St. Etienne in return for the use of the stored water for its domestic supply. The Ternay Dam, on the River Ternay, in southern France, was built in 1865 for the purpose of controlling the floods of the Ternay, and supplying water to the neighboring town of Annonay. The masonry dam is curved upstream and has a maximum height of 119 feet. The capacity of the reservoir is about 91,800,000 cubic feet, and the cost $204,372, or $2,226 per million cubic feet of storage. The third reservoir, on the Var River, near Rion, has a masonry dam 130 feet high.

SPAIN

The worst flood conditions in Spain are experienced in the eastern part, on the Segura River, the shortest of the important rivers of that country, which rises at an elevation of about 5,100 feet above sea-level and flows eastwardly for about 210 miles, entering the Mediterranean near Alicante. The drainage area is about 4,830 square miles, the maximum discharge about 52,000 second-feet, and the minimum discharge 106 second-feet. The annual rainfall is comparatively light, the maximum recorded being 16 inches and the minimum 6 inches. The climate is hot and dry, and droughts are of frequent occurrence, while floods are generally the result of cloudbursts or cyclones.

A special commission of engineers appointed by the Spanish government, with headquarters at the city of Murcia, has charge

of works for flood prevention and protection in the eastern provinces. The flood-relief work includes reforestation, dikes at low points, overflow canals, and storage reservoirs.

The flood-control reservoirs are also used for irrigation purposes during the summer droughts that are so prevalent in this rich agricultural region. Four of these reservoirs are now completed, and eight more are planned. The dams vary in height from 100 to 134 feet.

CANADA

The largest system of artificial reservoirs in the world is now being constructed on the Ottawa River in Canada. This river rises about 150 miles north of the city of Ottawa, Ontario, flows westwardly from its source for a considerable distance, thence southwardly for 100 miles, and then turns sharply to the east at Mattawa, where the junction with the proposed Georgian Bay Ship Canal would be made, and continues its easterly course for 150 miles, emptying into the St. Lawrence River at Montreal. The total length of the river is about 700 miles, and it drains an area of 56,000 square miles.

In the 505 miles of its course from the source to the city of Ottawa the river repeatedly widens out into long, shallow lakes, which form a series of steps from the Barriere Lakes, 1,100 feet above sea-level, to Ottawa, where the elevation is 140 feet. The stretches between the lakes are steep, and are broken by falls and rapids, the greatest drop being 80 feet, in the 15 miles between Lakes Timiskaming and Quinze.

Daily measurements of the discharge at Ottawa have been made since 1844, and show that the yearly mean since that date is 55,464 second-feet, the maximum average annual discharge being 68,584 second-feet, and the minimum, 35,583 second-feet. The maximum average discharge for 40 days in 60 years was 158,900 second-feet. The minimum recorded discharge was 25,000 second-feet and the maximum 230,000 second-feet.

The general plans for the reservoir system contemplate increasing the storage capacities of the numerous lakes by low concrete dams at their outlets, so that the daily flow of the river throughout the year may be kept as near the average of 55,000 second-feet as possible. The first three projects, which are now under construction, on Lake Timiskaming, Kipawa, and Quinze, have a combined capacity of 168,000,000,000 cubic feet. The total cost of these three reservoirs, including surveys and land damages, is estimated at $728,000, or only a little over $4 per million cubic feet of storage.

These reservoirs, while they are an important part of the proposed Georgian Bay Canal project, are being constructed independently of that plan, because of their great benefits in the prevention of flood damage and in the improvement of the river for navigation, for water power, and for industrial and domestic supply.

MISSISSIPPI RESERVOIR SYSTEM

The largest artificial reservoir system in the world, except that under construction on the Ottawa River in Canada, is that at the headwaters of the Mississippi River, where the levels of some of the innumerable lakes have been raised by damming up their outlets, and enormous storage capacity created at very small cost. These reservoirs were first reported upon officially by General G. K. Warren in 1870, and the investigations showed a total available storage in the States of Minnesota and Wisconsin of 174,000,000,000 cubic feet. Detailed surveys followed, and actual construction began in 1881. The combined capacity of the five reservoirs constructed is 93,400,000,000 cubic feet, and their total cost was about $750,000, or only about $8 per million cubic feet of storage. The dams were originally timber cribs, but have recently been rebuilt of concrete. The remainder of the available storage reservoirs have never been constructd, but, if they were, an eminent authority states that they would be "sufficient to control absolutely the floods of the Mississippi for a long distance below St. Paul, and to improve the navigation of the upper river very materially, while their value for industrial purposes is almost beyond estimate."

The foregoing abstract, being Appendix No. 5 of the report of the Flood Commission of Pittsburg, Pa., dated 1911, shows beyond question that flood prevention through the construction of regulating reservoirs is demonstrated to be a success in many localities. Particular attention is called to some of the smaller streams—as, for example, the Wupper, the Ruhr, the Rur, and the Weiseritz in Germany; the Wien River in Austria; the Furens, the Ternay, and the Var Rivers in France, all of which have small drainage areas and are fairly comparable as to size with our own Cherry Creek, although generally considerably smaller. Attention is also called to the cost of storage per million cubic feet. On the most of these small streams it will be seen that the cost is much greater than the cost for Cherry Creek, which, without taking benefits into consideration, has been given as not to exceed $2,000 per million feet of storage.

It is not necessary, however, to go so far abroad to see the advantages of stream regulation through reservoirs. There are numerous streams in the western United States where water has been stored primarily for irrigation, resulting, however, in practically the regulation of the streams. This condition of affairs now prevails to a great extent in connection with the South Fork of the South Platte, the Poudre, the Big Thompson, and other tributaries of the South Platte, North Platte through the con-

struction of the Pathfinder Dam, Salt River through the Roosevelt Dam in Arizona, and hundreds of other instances that might be given. Indeed, complete control of stream flow on many streams has been practically attained both for irrigation and for power purposes. There seems to be no reason whatsoever why the same end may not be attained for flood relief.

The report of the Flood Commission of Pittsburg, Pa., is a monumental work of two volumes, including maps and illustrations, and contains a vast amount of information, including abstracts from other papers and reports relative to flood control, with a complete bibliography of the subject, as well as a complete discussion of the Pittsburg situation. All who are interested in the subject are referred to this report for further information along these lines.